Pressure Digest

"PLASTIC FORMING OF METALS . . .
Where Are We Now and Where Are We Going?"

a talk presented by

Alexander Zeitlin, *President*

ENGINEERING SUPERVISION COMPANY

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MR. ZEITLIN IS PRESIDENT OF ENGINEERING SUPERVISION COMPANY, THE ENGINEERING SUBSIDIARY OF F. H. McGRAW & COMPANY.

I. INTRODUCTION

It is a great honor to have been chosen by your committee to submit to you a paper on the trends in the metal forming industry, and I am well aware of this honor. In preparing this presentation I have tried to illustrate my report by examples referring to the products of various builders of equipment. Obviously, some of the examples refer to the project I was closely connected with. I would like to quote from my speech made on December 5, 1951 at a meeting of the Aircraft Industries Association:

> "The choice of illustrations of our own
> "design does not mean that we are the
> "only builders of heavy presses; un-
> "doubtedly, other press builders would
> "be able to present to you similar illus-
> "trations based on their own design."

This quotation does not detract in any way from my conviction that the engineering team of Loewy Construction Company which I was privileged to manage during the Heavy Press Program, is an outstanding organization. I consider myself extremely fortunate that now at Birdsboro I am a member of an equally outstanding team.

I think the timing of this meeting was very well chosen. Just a week ago the last of the four forging presses of the Heavy Press Program went into operation. Most of the extrusion presses are operating and this is the right moment to stop and look at where we are, and try to lay out a route along which we, in my opinion, ought to proceed.

II. THE KNOWN AND THE UNKNOWN

Slide #1 It is customary to report the total knowledge acquired by mankind by the area of a circle, as shown on the first slide, and to have the unknown represented by the area outside the periphery of the circle. This analogy seems to me to fit the situation quite well. First of all, it shows that our perceptions of the unknown are confined to the thin line of the circumference of the circle. From the area of the known we can perceive and understand only the thin layer of the unknown which is just beyond the circle's periphery. The rest of the unknown area is beyond not only our knowledge and reach, but even the plainest and most general conception of what is hidden there.

The second observation would be that, as our knowledge, represented by the area of the circle, grows, so grows the periphery of the circle. In other words, the more we know, the more grows our awareness of the things unknown. Of course, the area of the circle grows faster than the circumference. Still, the circumference grows plenty fast enough.

It could be interesting to contemplate how fast the area of the circle grows. I believe that as a first assumption we can postulate that the larger our knowledge -in other words, the larger the area of the circle - the more possibilities we have to acquire additional knowledge, and consequently the faster the circle will grow.

Assuming that the rate of growth is proportional with the radius of the circle, we will find that during a small element of time dt, the radius R will grow by a small amount of dR, and since we have just assumed that the rate of increase of radius is proportional with the lapse of time, we can write the equation of dr = Rdt.

Resolving this equation by methods of differential calculus, we come to the equation of $R = Ke^t$.

$$\frac{dr}{R} = dt$$

$$\int_{R_1}^{R_2} \frac{dr}{R} = \int_{t_1}^{t_2} dt$$

$$\int R^{-1} dr = \int dt$$

$$\ln R = t + C$$

$$R = ke^t$$

From this equation we derive the realization that the ratio of areas for any interval of time can be determined by the formula $e^{2(t_2 - t_1)}$, while the amount of the unknown that we are aware of is determined by the formula: $e^{(t_2 - t_1)}$.

So much for mathematics, and I promise not to use mathematics beyond a multiplication table in the rest of my speech. I thought, however, I should point out that the conquest of the unknown is an arduous uphill fight in which only a thin line of the unknown can be attacked at any one time. Areas we do not know anything about, such as the areas well beyond the circle's periphery, cannot be conquered; they are just plain meaningless to us at any given time. Only geniuses like Leonardo da Vinci, Newton, or Edison, can jump slightly beyond the thin line enclosing the circle.

As a consequence, when talking about the direction in which we are going, we can barely visualize the trend for the next ten years, and you will understand, therefore,

that my attempt to look into the crystal ball must of necessity be limited to the outlook from where we are now standing. I feel that a look back at the stretch of the road we covered in the last five years or so may be very helpful when trying to extrapolate into the future. We cannot, of course, cover the entire field of plastic forming of metals in one speech, and I must of necessity confine myself to some representative examples.

III. CLOSED DIE FORGING PRESSES

In selecting our problem, let us start with the closed die forging press as a general purpose machine. I am referring to the closed die forging press as a general purpose machine, because later on I will show some examples of specialized machinery.

Slide #2 First of all, I would like to show the photo of the German 30, 000 Ton die forging press. This press was designed by Mr. Albers, now Chief Engineer of Loewy Construction Company. Actually, this press consists of two 15, 000 Ton presses placed back-to-back and joined by a movable platen. From his experience with this press -which was a giant press at the time it was designed and built - Mr. Albers gained the conviction that presses of this size, and certainly larger presses, should consist of simple fabricated elements which can be readily stress-analyzed. His thinking resulted in the laminated design of the 35, 000 Ton and 50, 000 Ton presses which I will show you later. Coming back to the

German press, I want to point out that the technique in the manufacturing of castings did not stop on the level of the art available in Germany in 1940. The following slides show the manufacturing and the final appearance of the 50,000 Ton Mesta press which has basically the same design concept as the German 30,000 Ton press.

Slide #3 The first slide shows the artist's concep tion of the press. You can see the eight cylindrical columns, each carrying a load of approximately 6000 tons. You can see the large castings used in the design of the platen, the movable crossheads and the crown. Again the basic idea is, doubling up of two 25,000 Ton presses and joining them by lower and upper platens.

Slide #4 The next slide shows the machining of a portion of the upper crosshead with the holes for four cylinders and four columns.

Slide #5 The next slide shows the transporting of this crosshead on a flat car.

Slide #6 The next slide shows the portion of the lower crosshead being machined on a horizontal boring mill.

Slide #7 The next slide shows one of the eight tie rods being machined on a lathe especially built for this job. We can say that this lathe is also part of the Heavy Press Program.

Slide #8
Slide #9 The next two slides show the 50,000 Ton Mesta press installed in the Cleveland Works of ALCOA.

The main lesson we can draw from these pictures is, that what seemed practically impossible in 1940, and even in 1948, was made possible by the development in the art of making castings by 1954/55.

Slide #10
Slide #11 The next two slides show the 35,000 Ton Loewy press designed by Mr. Albers. This is the only forging press within the Heavy Press Program which has side cylinders and which is, therefore, capable of doing upsetting and piercing work. On slide #11 you can see the wide column spread of over 19 ft. which again is a unique feature of this press as compared with all other presses of the Heavy Press Program.

Lady and Gentlemen:

A look back at the development of castings from the German 30,000 Ton press to the 50,000 Ton press of Mesta, has indicated to us the tremendous progress made in this field from 1940 to 1955.

The following review of some of the problems on the Loewy presses will help us to forecast some future trends.

Slide #12 Slide #12 shows the lamination assembly of the Loewy presses. Actually, the slide shows the lamination assembly of

the 75,000 Ton press; the same design was used for the 35,000 and 50,000 Ton presses.

The design of the supports was changed on the basis of results of the stress analysis; however, this point is immaterial for our purposes. You can see on the slide two solutions contemplated by the designer for the fabrication of the laminations. One is the use of three forged laminations each 13'-1/2" thick; the other is based on the use of thirteen rolled plate laminations, each 3" thick. These laminations could have been rolled full-length; however, the length of the laminations would have required moving some of the auxiliary machinery which was in the way in the shop where the rolling mills were installed. It was impossible to arrange for this necessary moving during the Korean war, and, therefore, we contemplated the fabrication of the laminations out of these pieces which would be welded together. At the time of the decision the use of welded pieces for these laminations was frowned upon, and the idea was abandoned. The laminations were forged: eighteen for the 50,000 Ton press, and twelve for the 35,000 Ton press,.

Slide #13 The next slide shows the ingot used for the forging of each of the forged laminations. The ingot is 108" in diameter. The total length is 26 ft. The ingot was not allowed to cool down after pouring; it was kept hot until it was sufficiently

forged down to eliminate the danger of cracking due to excessive thermal stresses. One would think that this ingot represents the ultimate size of ingot that can be managed, and that, therefore, we have reached the limit in manufacturing of forged laminations. I am confident, however, that, should the industry need larger laminations -for instance, for a 100,000 Ton press-, Bethlehem Steel, who forged all the laminations for the Loewy presses, could be induced today to produce an ingot 134" in diameter and process it in a similar way.

While, as I said, the use of weldings for laminations was frowned upon, the main crosshead beams were produced in three parts welded together, as shown

Slide #14 on the next slide. The center piece is a forging the two other pieces are castings.

Many valuable observations were made during the welding process. It would be very desirable, if the Air Materiel Command could arrange for a publication of a report on this matter.

The welding setup is a gantry, specially built for this job. It is also a part of the Heavy Press Program.

Slide #15 Trepanned cores were taken from the weldments for a metallographic investigation. The structure is shown on the next slide. The weldments were subjected to all kinds of tests. I am confident that no objections would be raised

today against welding the long laminations and, therefore, we have today two methods of manufacturing the laminated tie rods, - forgings and fabricated weldments.

Slide #16 Speaking of new methods of producing large elements of presses, I believe you will be interested in seeing the next slide. Forgings were difficult to obtain during the Korean war and, therefore, a thorough search was made in order to find some substitute method of manufacturing. The bad experience with large cast cylinders for comparatively high pressures eliminated castings, and this slide shows the actually used solution: this is a multilayer cylinder, which was manufactured by A. O. Smith Corporation for the 12,000 Ton extrusion press installed at Curtiss-Wright, Buffalo, New York.

This cylinder was thoroughly examined and subjected to all possible tests. It is in operation now and we are confident that this method will present substantial competition to forgings in the future.

Slide #17 The next slide shows a difficult problem which had to be resolved during the construction of the foundation of the 50,000 Ton press at Wyman-Gordon. The construction of this foundation was one of the most difficult problems and one of the most trying experiences during the entire program. We would not have seen it through successfully except for the moral support of the organizations represented by the two men sitting here on the podium: Col. Adams and George Motherwell. When difficulties threatened to shut down the

whole undertaking and crucial choices between alternatives had to be made, the Air Force and Wyman-Gordon, represented by Col. Adams and George Motherwell, showed their full confidence by letting us handle the situation the way we saw fit. It is a great satisfaction to me and to the entire team responsible for the job that the outcome proved this confidence was not misplaced.

Slide #18 I am showing slide #18 as an indication that the presses proper represent only part of the problem involved in the construction of a heavy press forging plant: the open area is the area where the presses are being erected. The rest of the building already under roof, is scheduled for all the auxiliary devices and secondary operations like inspection, heat treating, die shrinking, etc.

Relating the above examples to the theme of this report, we can say that the thorough engineering research and the willingness to stick out one's neck a little more each time, led us towards more economical methods of production and to our ability to produce better and more adequate machines.

Slide #19 The next slide, showing the outline of the four forging presses of the Heavy Press Program, indicates to us where we are today.

Now where do we go from here?

Slide #20 The next slide shows once more the two 50, 000 Ton presses and also my opinion as to where we ought to go from here. Contemplating the previously shown slides of the details of these two 50, 000 Ton presses, I have not the slightest hesitation in stating that a 100, 000 Ton press is feasible. Its design, stress analysis, fabricating, transporting, and erecting will offer problems, but they will not present any insurmountable difficulties. Using the language of the Air Force, "it is produceable, transportable, and operable." It has an economic and strategic justification. The dimensions of such a press are indicated by the two rectangles in the right portion of the slide. We did not try to prepare a complete design of a 100, 000 Ton press; however, our stress analysis indicates that the actual press will have dimensions somewhere in between the two rectangles.

In increasing the capacity of the press, we would want to keep the increase in the dimensions of the bed to a minimum. What we would actually want, would be to increase the effective forging area that the press would be capable of. You must realize that 50, 000 tons can be applied usefully to effective forging areas of not more than perhaps 3500 to 4000 square inches, since each square inch of the effective forging area needs a pressure in the neighborhood of 15 tons, and sometimes much more. In other words, while the press beds of the 50, 000 Ton press have a forging area of 360 square feet, or 52, 000 square inches, only about 8%

of this area can be subjected to the forging pressure while producing useful parts. Obviously, the doubling of the rating of the press which would allow the doubling of the effective forging area, would be especially attractive if it were not accompanied by a substantial increase in bed area. Mr. E. V. Crane of Bliss has suggested an arrangement of the hydraulic system which would actually allow the accomplishment of the just stated objective. Prior to Mr. Crane, somewhat different arrangements were suggested abroad. We feel, therefore, that not only can a 100, 000 Ton press be designed and put to work, but that the increase in the bed area will not be substantial.

III. EXTRUSION PRESSES

Slide #21 The next slide shows the basic structure of an extrusion press. You see here on top on the right the hydraulic system and on the left the so-called "business-end"; you see the container into which the hot billet is inserted; you see the die through which the hot billet is pushed by applying the pressure of the hydraulic system. The rest are structural members which complete the arrangement of the press.

At the bottom you see a similar press with the difference that this press has an auxiliary cylinder in the back which can move an independent mandrel arrangement inside the hollow extrusion stem. This arrangement allows for piercing of solid billets

and for manufacturing of tubes.

The concept of a modern extrusion press originated in Germany in the early twenties. Today the extrusion presses represent a standard tool used throughout the ferrous, non-ferrous, and light metals industry. Of the Heavy Press Program presses, four were built by Loewy Construction, and one each by Lombard, Schloemann and Hydraulik There are, of course, many more companies building extrusion presses today.

The pressures required in the extrusion are much higher than the pressures needed for closed die forging.

Actually, at the extrusion temperature of 750 to 900 degrees F., a 4000 to 5000 psi would bring aluminum into a plastic state and make it, theoretically, creep or flow. However, the friction losses along the area of contact between the billet and the container; between the billet and the die, and the friction within the metal itself, are such that the actual pressure required is in the range from 60,000 psi and higher. As an example, a 6000 Ton press could not extrude billets with more than 200 square inches cross-section area.

Slide #22 The next slide shows the maximum size of a billet that could be extruded on a 25,000 Ton extrusion press. Actually, the largest press of the Heavy Press Program is only 14,000 tons, since the 20,000 and 25,000 ton presses of the program were cancelled in the midst of the work.

The largest billet that could be used on a 14, 000 Ton press has probably a diameter of around 28" or 30". Any shape produced on an extrusion press cannot exceed, generally speaking, in its outer dimensions the size of the billet and, as shown on the slide, a reasonably high extrusion ratio reduces the area of the cross-section so that a 25, 000 Ton press could extrude shapes with the cross-section equivalent to a 7" bar. This is not very much, but nothing could be done about it until recently. I have made this qualification "until recently" twice in succession now, - one referring to the maximum pressures obtainable in extrusion, the other one referring to the limitations in the size of the billet. In both cases we have made extraordinary progress in the last few years, and we can see avenues of further progress in the near future.

First, with regard to pressures:

<u>Slide #23</u> The next slide shows the stress distribution in a billet container made of a single solid tube. You can see that actually only the internal fibers are fully stressed, while the outer fibers carry a much smaller load. This is due to stress distribution in a solid tube, and this situation cannot be helped seemingly. The situation reminds me of General Kenneth B. Wolfe, one of the spiritual fathers of the Heavy Press Program. When his aids would tell him that something could not be done because it was contrary to regulations, his answer to them was: "You are not here to tell me that it cannot be done because of regulations, but to tell me how it can be done in spite of regulations." Now, we cannot change the laws of physics either, but we can

try to reach our objective in spite of them. In this particular case we can do so: by subdividing the solid tube into compound structures consisting of several layers, we can make each layer work like a separate solid tube and make their fibers assume a more evenly distributed stress pattern.

Furthermore, by shrinking the tubes one onto the other, we can introduce an initial stress of the opposite sign so that this initial stress will reduce the total stress during the extrusion. As I said before, until recently the operators were satisfied with extrusion pressures of 60, 000 and up to perhaps, 100, 000 psi. A couple of years ago they were confronted with new air frame designs incorporating extruded shapes for the manufacture of which much higher pressures were required.

Steel used for the manufacture of containers had a yield point of 110, 000 psi at the extrusion temperatures and obviously the press builders were initially reluctant to even consider the needs of the operators for higher pressures. Some observations made in the New Kensington Laboratory of ALCOA showed however, that containers can withstand a much higher pressure than the yield point of the steel of which they were made. It became obvious to all concerned that some of the container fibers were stressed beyond the yield limit. A thorough development based on stress-analytical studies, led to a revised concept of the problem which allows now for the designing of

containers for pressures well in excess of the in the meantime improved yield limit of container steel of 120, 000 psi at 800 degrees F. As a matter of fact, containers for extrusion pressures of up to 190, 000 psi can be designed, built and successfully operated. Let's see first what would happen if we try to subject the container to stresses beyond the yield limit. Obviously, the individual fibers will not take any load beyond the yield point and the excess amount will be just referred to the next fiber stressing it to the yield point limit. The rest is then transferred to the next fiber and so on, until the entire excess amount is taken care of.

Slide #24 — The next slide shows the distribution of pressure along the billet. The container itself is omitted, but you can see the billet, the die, the pressing stem and the dummy block which protects the pressing stem from wear. You can see the higher pressure exists only in the neighborhood of the dummy block and drops off toward the die under the influence of friction between container and billet, as well as intercrystalline friction within the billet.

Slide #25 — Now, the next slide shows on the right hand the already familiar diagram of stress distribution, this time, however, with the tips spread over a comparatively large width. It is obvious that the fibers corresponding to the flat portion of the stress curves, are in plastic state. Fortunately, the area of high stresses is limited to the neighborhood of the dummy block and the left portion of the slide

indicates the approximate extent of the plastic regions.

The stress analysis in the case of pressure varying along the axis cannot be accomplished by elementary means; however, as mentioned before, studies have shown an approach to the problem and I am glad to say that the problem can be considered as solved today.

Slide #26 The next slide shows the container for the 12,000 Ton press installed at Curtiss-Wright in Buffalo.

An equally important development was directed towards modification in billet shape.

Slide #27 On the next slide you can see on top the r ound billet and the size of the extruded bar. Of course, instead of the bar, another shape with an equal cross-section could be extruded, but, as stated before, generally speaking, the extrusion would have always to remain within the billet circle.

Mr. Carl Brauninger, who at that time was working for the Air Materiel Command, and who is now Manager of the Extrusion Division of the Dow Chemical Corporation, was the first to point out that the pressure produced by the press could be applied to a billet with an elongated cross-section rather than a circular one. The specific pressure would remain the same. The resulting extrusion could be much wider, although much thinner. Loewy Construction Company undertook a development project under the sponsorship of the Air Materiel Command; the actual extrusions from rectangular billets were per-

Slide #28

formed at the Reynolds Metals Plant in Phoenix, Arizona, and the next slide shows an amazing extrusion of close to 12" width made with an extrusion pressure of about 2000 tons. Generally speaking, a 12" wide extrusion would require a billet in excess of 12" diameter, which in turn would require a press of well over 3000 tons capacity.

Summarizing again the present stand of art, we can say that the rating of extrusion presses can be utilized much better due to the extrudability of rectangular billets.

Slide #29

The next slide shows the maximum billet size for cylindrical and rectangular billets for various press ratings. You can see that, while an 8000 Ton press can extrude a cylindrical billet of 20" only, the same press --properly designed-- can extrude a 35" wide rectangular billet. The corresponding figures for the 12,000 Ton press are 26" and 45".

This is where we are now. We could, however, build a 20,000 Ton press with a 54", or even 60" wide rectangular billet today, and I have great hopes that within ten years we will be at the 40,000 Ton press with a billet width of 75".

The introduction of the elongated billet shape is an event, the importance of which cannot be over-emphasized. It opens completely new horizons for the extrusion process. Close attention to this process should be given by operators and users of extrusions.

IV. STEEL AND TITANIUM

The application of closed die forging and extrusion presses to steel is an accomplished fact; the application of extrusion methods to titanium, however, is still not completely developed and will require the continuation of diligent work that has been proceeding already for several years. It is my opinion that we will develop the necessary know-how in perhaps two more years.

V. PRECISION FORGINGS

Two more avenues of advance into new territories should be mentioned:

The first concerns precision forgings, i.e., forgings produced to finished dimensions. Some of you will remember that at the A.I.A. meeting in 1951 the basic concept of precision forgings was seriously questioned. Today, medium size precision forgings are manufactured in production runs.

Tomorrow, I mean in a year or two, we will undoubtedly have large forgings produced to finished dimensions.

VI. EXTRUDED END PRODUCTS

The other avenue of progress is the production of extruded end products rather than the conventional long spaghettis: items like gun barrels, propellers, and many others can be produced on an extrusion press quite satisfactorily and economically. The process was proven on several occasions; the successful extrusion of gun barrels with an integral firing chamber for 57 and 75 mm is being followed up

by a new project on the 90 mm tank gun. It is my opinion that we will have many more end products produced on extrusion presses within the next three to five years.

VII. LARGE BILLETS AND INGOTS

The large presses will require large billets. The present method of casting the billets in a conventional direct chill casting machine is not very satisfactory. The control of the speed and temperature is not very accurate. I am submitting on the next slide:

Slide #30 some suggestions for a better design of the D. C. casting machine. You can see on the left the conventional design of the machine with water being sprayed on the short mold from which the solidified billet emerges. On the right you see the principle of a machine with a close control of the temperature distribution along the cast billet. You see two spray rings with wipers removing the water just below the spray and an auxiliary heating arrangement in order to reduce the cooling rate of the billet in the lower portion. I should mention that Kaiser Aluminum Company has successfully cast billets of 75S alloy up to 32" in diameter. I do not know what modifications of the conventional D. C. machine was made by Kaiser; however, the results are excellent. We can say, therefore, that the solution of large billets for extrusion presses is here and that the future will bring forth further

refinements. The problem of providing large ingots for rolling mills has not advanced to that point as yet.

Slide #31 The next slide shows two ingots, one on the left is a 10,000-lb. ingot which is more or less the limit available today on a production basis. The requirements, however, are represented by the ingot on the right, which is a 50,000-lb. ingot. The reason for the need of large billets is the heavy plate used in air frame production. The air frame manufacturers require plate 120" wide, 6" thick, and about 40 ft. long. This plate will weigh close to 50,000 lbs. and, therefore, would have to be rolled from a billet of adequate weight.

One of the difficulties in casting heavy billets are internal stresses which accumulate across the width of the ingot and lead to its cracking along the center line. I believe that a modification of the D.C. casting machine, as suggested on the previous slide, or some similar arrangement which would reduce the thermal stresses, would help to produce billets of the desired size. The problem will not end there, however.

VIII. STRAIGHTENING OF PLATE

Slide #32 The plate will have to be straightened and the next slide shows one of the problems in straightening of heavy plate by stretching. A plate of 6" thickness, and 120" width would require a stretcher of 20,000 tons. Kaiser Aluminum Company initiated the trend towards larger and bigger stretchers two years ago by installing a 2500-ton

stretcher in their Trentwood Plant. They modified the stretcher into a 5000-ton machine. It is in operation now. It was built by Watson-Stillman, and built, by the way, apparently with an exceedingly high safety factor since this 2500-ton machine is not breaking down when operated as a 5000-ton unit. The trend was continued and 8000-ton machines were designed and proposed by several companies, among others United, Loewy, Watson-Stillman, Birdsboro, and several others. Two machines of this size are being built at present. Kaiser Aluminum Company is talking about a 20,000 Ton stretcher. They will be pioneering in the right direction if they go ahead with that project.

Some of the problems that have to be solved are shown on this slide. First of all, the areas into which the serrations are biting, are marked and must be trimmed off. For a 6" plate this means the loss of 18" at each end, or a total loss of 3 ft. Three feet, 6" thick and 120" wide weigh 2600 pounds. Considering the limited weight of currently cast ingots, the loss of 2600 lbs. represents a great hardship, which can probably be solved only by the increase in ingot weight.

The other problem is the transfer of the 20,000 Ton stretching effort into the thickness of the plate without introducing excessive local stresses which would crack the plate during stretching. New ideas are needed for the design of the jaws and they will have to come in the near future. The generally accepted explanation of the mechanism of stretch-straightening is, that the stretching effort brings the stresses

in the metal to the yield point level and that, having reached the level, the stresses re-distribute themselves over the cross-section so as to achieve an equilibrium. When the stretching force is removed, the residual stresses remain evenly distributed over the cross-section and the plate remains straight.

I cannot suggest any better concept for the performance of the stretch-straightener. However, I submit two facts which seemingly cannot be explained by the generally accepted theory.

The stretched sheets are quite often sculptured by putting them on metal-cutting tools and hogging out various grooved patterns. If the generally accepted explanations were true, then this one-sided hogging would certainly destroy the equilibrium of locked-in stresses and would cause a severe warping of the plate. While a certain amount of warpage has been observed in sculpturing, the actual amount of warpage is much less than one would expect.

The other observation refers to plates cladded on one side by a metal of different physical characteristic; (for instance, carbon steel cladded by stainless steel). While the modulus of elasticity of both steels is practically identical, the yield limit is quite different. Still, one can produce beautiful level plates by stretch-straightening carbon steel plates cladded with stainless steel on one side.

This situation reminds me of John Stuart Mills, having lectured a college class one day on a new theory developed by him. At the end of the lecture he asked the students whether they had any questions, and one of his students got up and pointed out very respectfully that the facts were not in accordance with the Professor's theory. Mills looked at the student and said: "Too bad for the facts." This attitude may be acceptable in the field of philosophy or economics, but unfortunately, it does not work in engineering, and I am submitting the above mentioned facts to our stress analysts for further consideration.

The straightening of plate in roller straighteners represents another stress-analytical problem. The straightening process in a roller straightener is similar to a demagnetizing process. As you know, in order to demagnetize a piece of steel, we bring in into an alternating magnetic field which at the beginning of the demagnetizing process is stronger than the residual magnetism in the piece of metal. Under the influence of the oscillating magnetic field, the piece goes through a series of hysteresis patterns. By slowly decreasing the strength of the field, we can remove the residual magnetism completely. In the roller straightener we proceed similarly by putting the plate through a series of rolls adjusted in such a way that the work piece is subjected to bending stresses. The first rolls are adjusted so as to produce bending stresses in excess of the locked-in forces which cause the warpage. Little by little, as the piece proceeds to move between the rolls, the appropriately set rolls produce smaller and smaller

bending stresses until the piece emerges at the exit side completely free from stresses and entirely plane.

The main problem with which we are confronted here, is the presence of stresses perpendicular to the line of motion, which are originated by the Poisson effect. As you know, elongation in one direction produces a contraction in the perpendicular direction. Any contraction produces a perpendicular elongation. You can easily demonstrate it by bending a thick piece of rubber.

This crosswise deformation produces in turn a warpage resulting in a saddle shape with the depression on the elongated side.

Now, when you roller-straighten a thin plate, such a plate is elastic enough to follow the deformations described above, without damage to the plate. However, a thick plate is too rigid to warp and, if we try to roller-straighten a thick plate very vigorously, the plate, instead of straightening, may crack in the center. The increase in the number of rollers in a straightener will alleviate this condition, but will not solve it completely, since the initial effort must be higher than the locked-in stresses.

IX. SPECIAL PURPOSE MACHINES

I mentioned at the beginning of my presentation that the general purpose machines, such as the closed die forging presses, extrusion presses and rolling mills are being supplemented by specialized machinery.

Slide #33 The next slide shows the concept of a specialized combination machine for forging and extrusion in one step. I would actually call it rather extrusion and upsetting.

Slide #34 Next slide shows the principle of a machine by Dr. Altwicker and Mr. Brauninger, which is capable of performing a series of operations, like closed die forging, upsetting, piercing, and step-extrusion forward and backward. The value of this suggestion for the manufacturing of intricate hollow shapes extensively used in the landing gear industry cannot be over-estimated. At present, steel ingots of 28,000 lbs. are cropped into billets of 22,000 lbs., then hammered into rough forgings of 9000 lbs., and then finally machined into an 1800-lb. cylinder. You can readily see that a machine built in accordance with the principle shown on this slide, would start with a slug of certainly not more than 2000 lbs. and would pay for itself within a short time just out of the savings on metal.

It is my opinion that we will be forced to use specialized machines of this and similar type within a few years.

Another specialized type of machine is the roll-forming machine developed by A. O. Smith. The machine consists basically of a flat die reciprocating along a smooth rotating roll. By passing between die and roll, the metal is shaped.

Slide #35 You can see on the next slide various shapes that can be produced on the roll-forming machine by appropriately shaped dies.

Slide #36 The next slide shows an end-product made of roll-formed parts. It is my opinion that machines of this type will be extensively used in the future.

The above examples lead us to the conclusion that, as the manufacturing process becomes more and more complicated, it will be necessary for the machine builder to think more and more in terms of a complete production line rather than in terms of an individual machine.

X. RECOMMENDATIONS

I take the liberty of closing my presentation by submitting a list of projects that I feel would speed our advance into the unknown and help us to proceed in the desired direction. The suggestions are subdivided into recommendations for research and development work as well as recommendations for some new facilities. I fully realize that the great progress achieved during the Heavy Press Program was due to the enlightened guidance and leadership of the Industrial Resources Division of the Air Materiel Command of the United States Air Force. Many of the suggested projects are probably being considered by them already.

A. SUGGESTIONS FOR RESEARCH AND DEVELOPMENT PROJECTS:

(1) Continuation of the development of large circular billets for extrusion presses. The first

objective should be the casting of 75S billets up to 35" diameter on a production basis.

(2) Continuation of the development of large ingots for rolling mills. The first objective should be the casting of a 25,000-lb. ingot of 75S alloy, 60" wide, 20" thick, at least 15 to 18 feet long.

(3) Continuation of various efforts for the development of new methods for producing flat and coiled stock with by-passing the ingot stage.

(4) Continuation of the development of the know-how in extruding rectangular billets.

(5) Continued research on extrusion of titanium, making sure that an exchange of information is established not only among all companies engaged in projects financed by the government, but also between these companies and the rest of the industry. Thus far, there has not been any joint compilation and evaluation of results.

(6) Continued research on lubrication of titanium and steel extrusions.

B. SUGGESTIONS WITH REFERENCE TO MACHINERY:

(7) A study preliminary to planning and installation of a 100, 000 Ton closed die forging press, either by expanding one of the existing facilities, or by reinstating and modifying one of the partly finished facilities.

(8) Study advanced designs of extrusion presses of 20000 tons capacity and, depending on the result of the study, the construction and installation of a modern up-to-date 20, 000 Ton press.

(9) Advance of the operational know-how and machine design for the secondary operations in extrusion and rolling mill plants; among others:

a) Stretcher-straightening operations on machines with a capacity of at least 20, 000 tons for plates 6" thick, 144" wide.

b) Roller straightener for plates of at least 144" wide, 6" thick.

(10) Development, engineering and installation of specialized machinery such as, for instance, a multiple operation press in which elements of landing gears can be produced to practically finished shape in one setup, or, a specialized extrusion press of a design which would facilitate upsetting and piercing operations.

(11) Make sure that the installations referred to in items 7, 8, 9, and 10 will be equipped to handle steel and titanium. It is my opinion that the new equipment should be installed in facilities open to all metals; aluminum, magnesium, steel, titanium.

(12) Research on controlling the die and tool temperature by heating and cooling. Such research to apply to extrusion and forging dies.

C. COORDINATION AND MANAGEMENT OF RESEARCH AND PLANNING:

I have one more suggestion to make and this is:

(13) Organization of an industry advisory committee on plastic forming of metals, consisting of representatives of the government agencies, research organizations, producers, fabricators, users, and machine builders, for the purpose of coordinating all research activities and the planning of new industrial facilities.

If this particular suggestion is accepted and followed through, we will really go places fast.

XI. CONCLUSION:

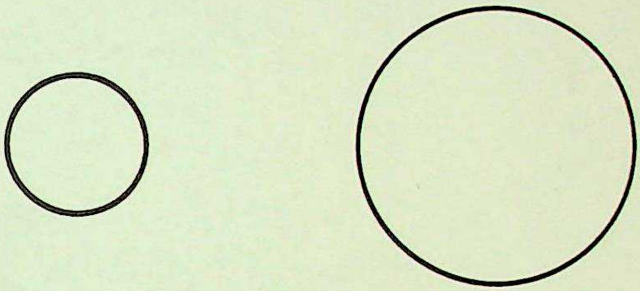
One last, but very important remark:

It would be a grave omission not to give credit to the United States Air Force, to its Air Materiel Command and, in particular to the Industrial Resources Division, for their indisputable leadership in the development of new manufacturing methods and in the exploration of new horizons. They have not hesitated to go ahead when a large segment of the industry was satisfied with the available knowledge and know-how. They have urged, implored, and also pushed; they have used sometimes candy, and sometimes the whip - but in all cases they were pointing towards more knowledge, better know-how, new methods, and deeper understanding.

There is an old story about a man meeting a stranger who was endowed with supernatural powers. They became friendly, and the stranger offered the man to take care of one most ardent wish. The man discussed the matter with the stranger and, having discussed health, fortune, long life, success, power, etc., came to the conclusion that the thing he wanted most, was to remain the way he was at that moment all the rest of his life; the stranger looked at him and told him that his wish would be fulfilled. The man went home, went to bed, and died the very same night. The obvious moral of the story being, that nobody can stand still and live, that life is a constant change and progress.

I think that members of the United States Air Force are very fortunate to belong to an organization that realized this simple truth very early, and has always lived up to it.

PRESENT FUTURE



$$\pi R_1^2 \qquad \left(\frac{R_2}{R_1}\right)^2 \qquad \pi R_2^2$$

$$2\pi R_1 \qquad \frac{R_2}{R_1} \qquad 2\pi R_2$$

$$dR = R\,dt$$

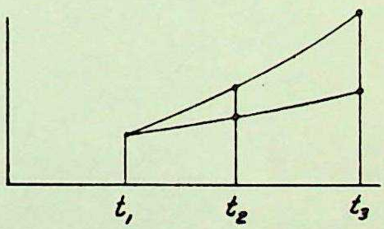
$$AREA = e^{2(t_2 - t_1)}$$

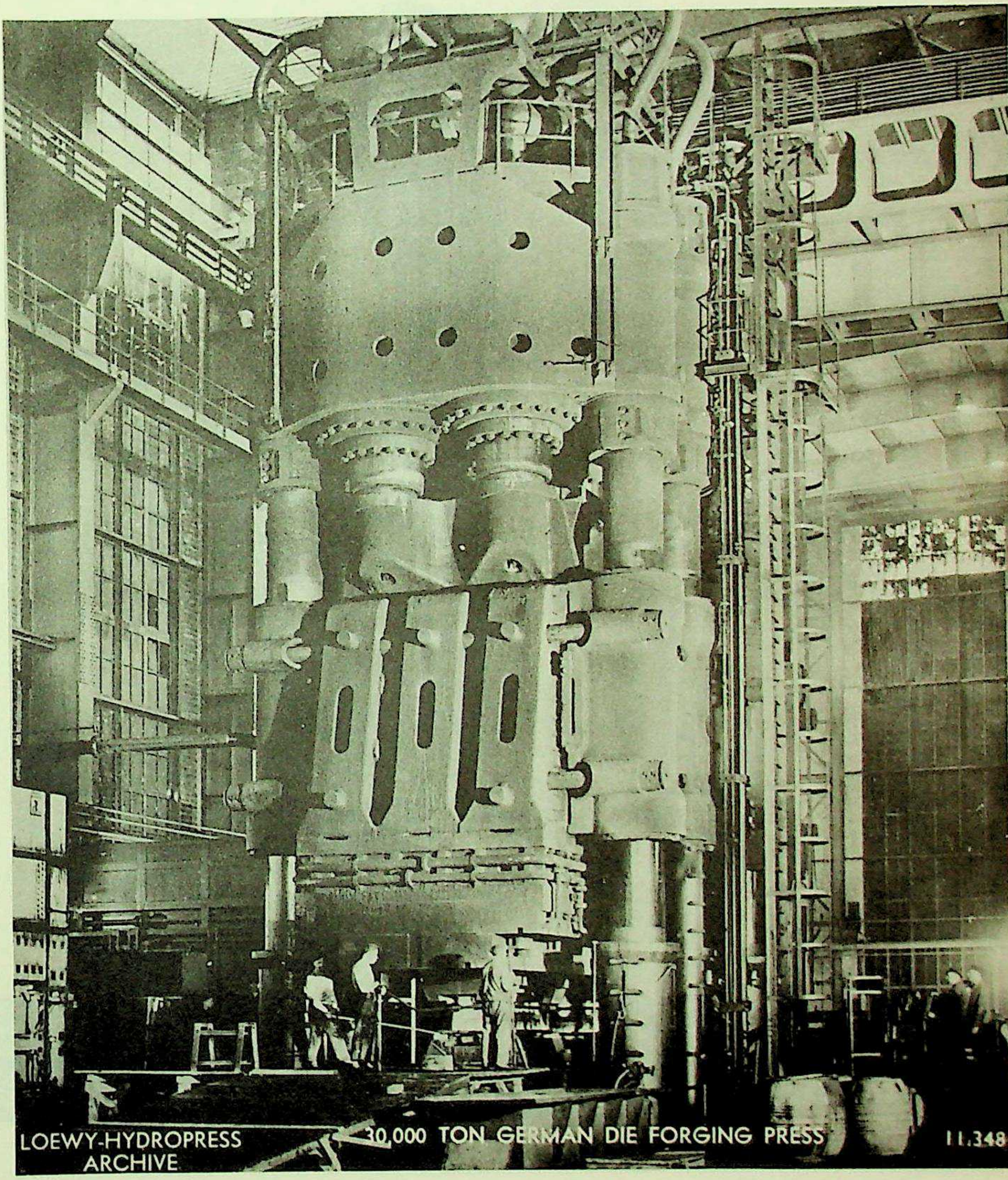
$$PERIMETER = e^{t_2 - t_1}$$

$$\frac{dR}{R} = dt$$

$$\ln R = t + C$$

$$R = e^{t+c} = e^t \cdot e^c = Ke^t$$

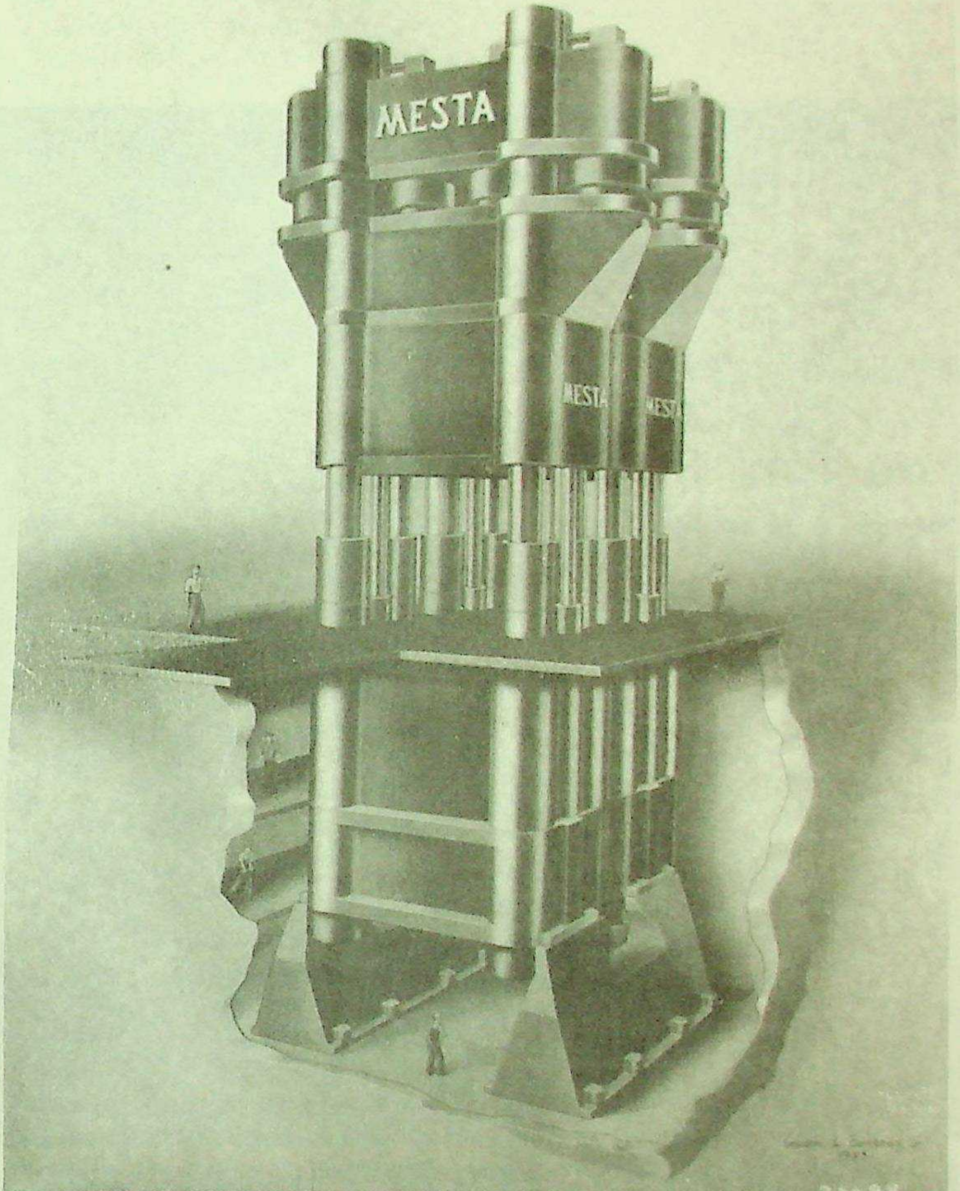




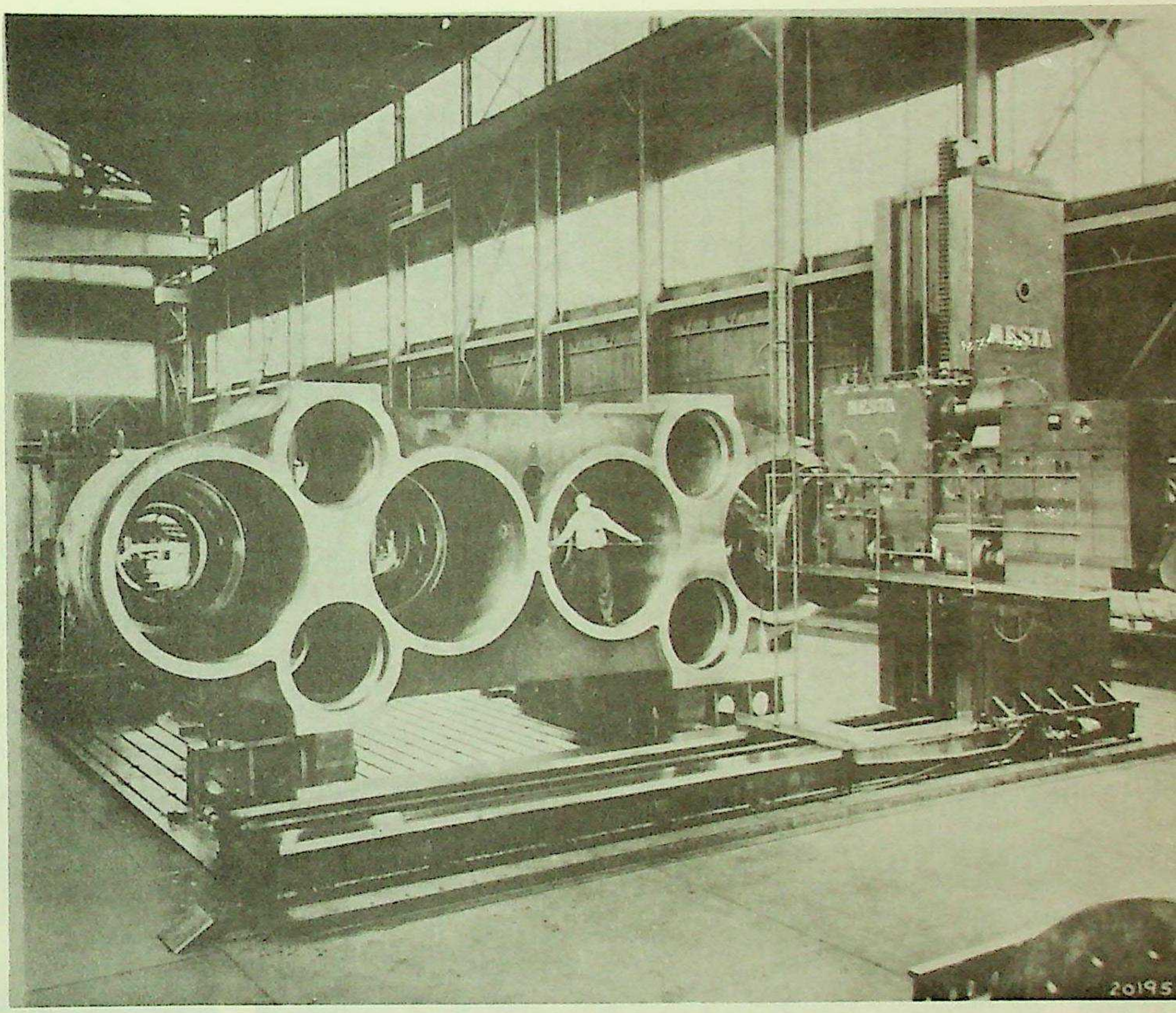
LOEWY-HYDROPRESS ARCHIVE

30,000 TON GERMAN DIE FORGING PRESS

11.348



MESTA 50,000 TON PRESS



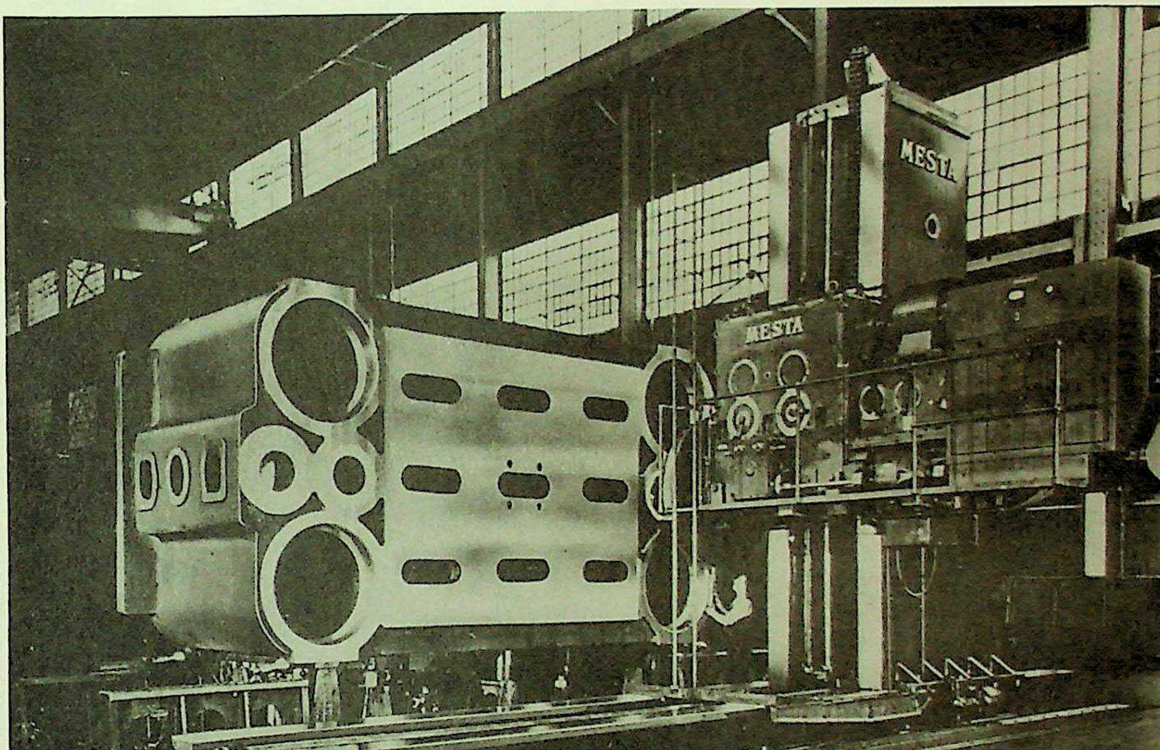
BIRDSBORO ARCHIVE

MESTA 50,000 TON PRESS

1

BIRDSBORO ARCHIVE

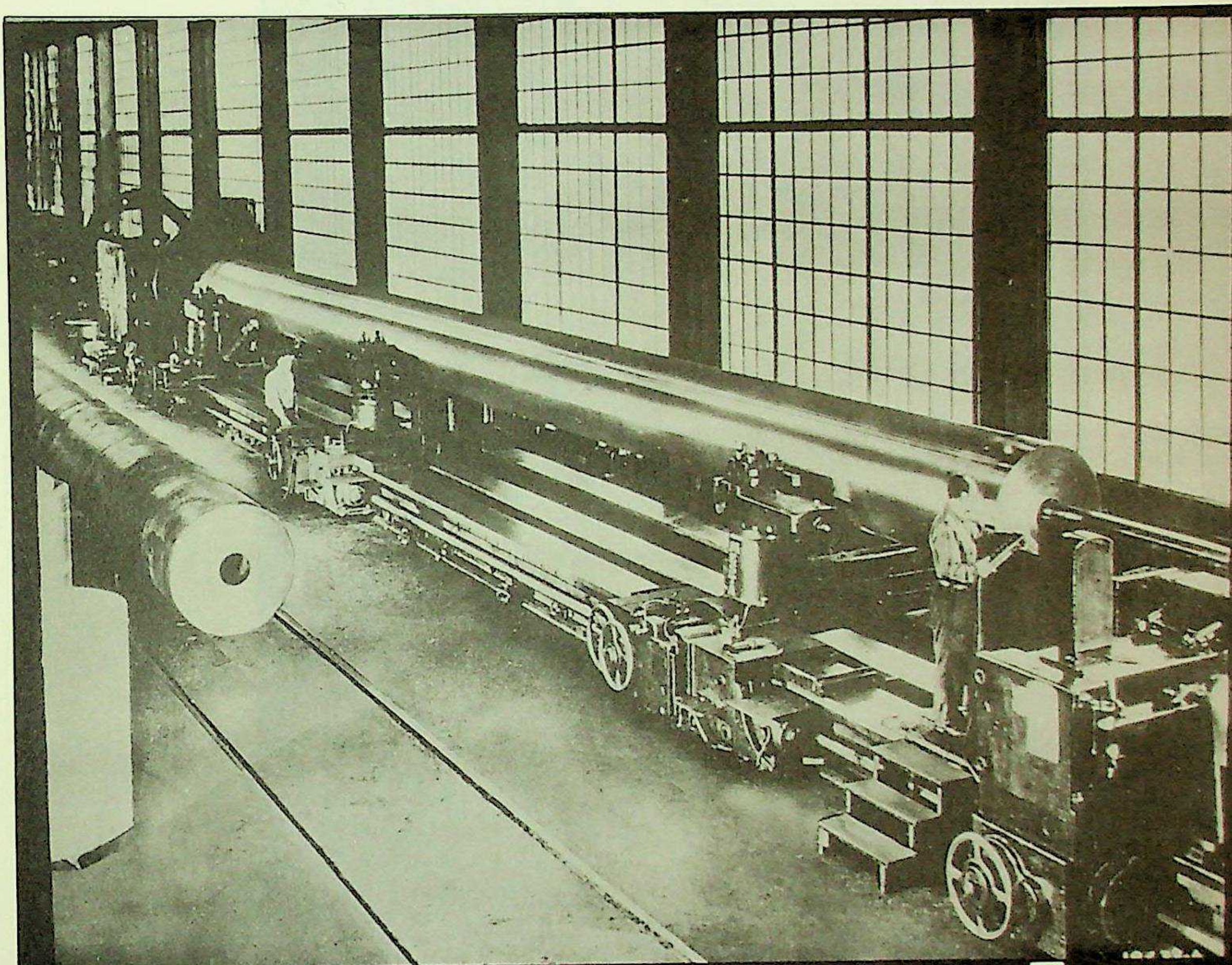
MESTA 50,000 TON PRESS



BIRDSBORO ARCHIVE

MESTA 50,000 TON PRESS

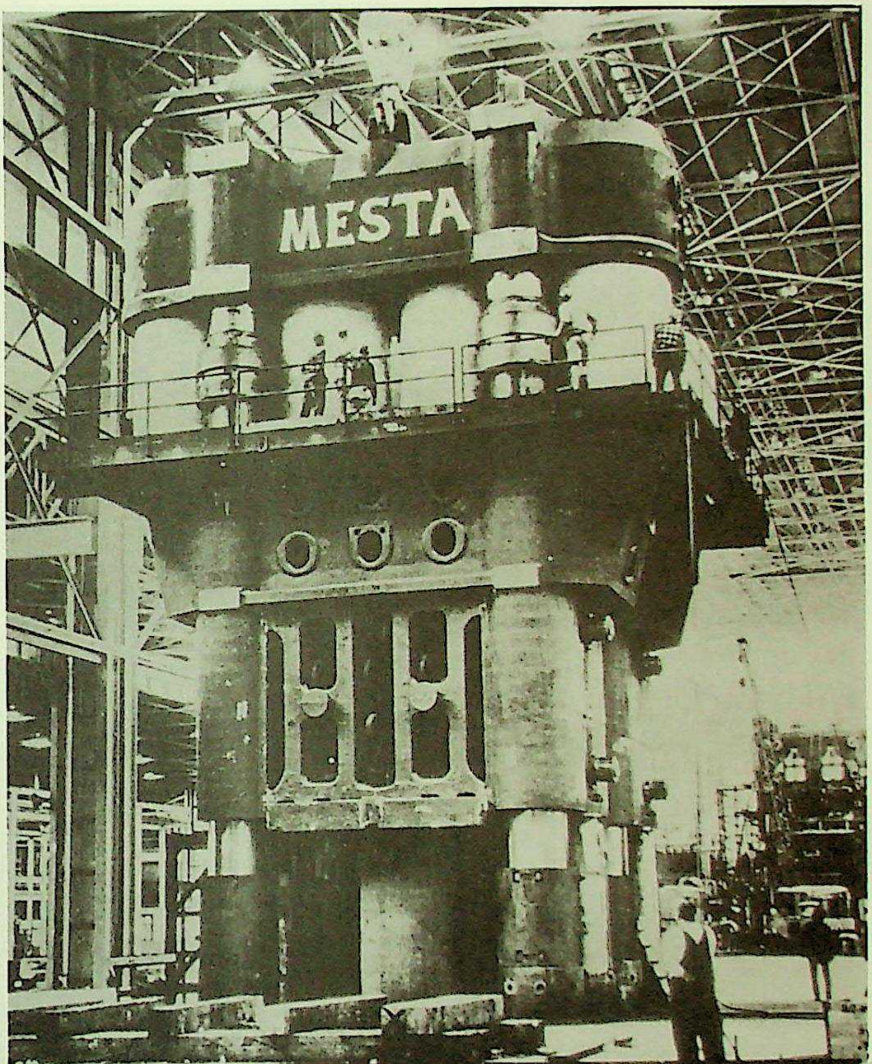
119



BIRDSBORO ARCHIVE

MESTA 50,000 TON PRESS

122



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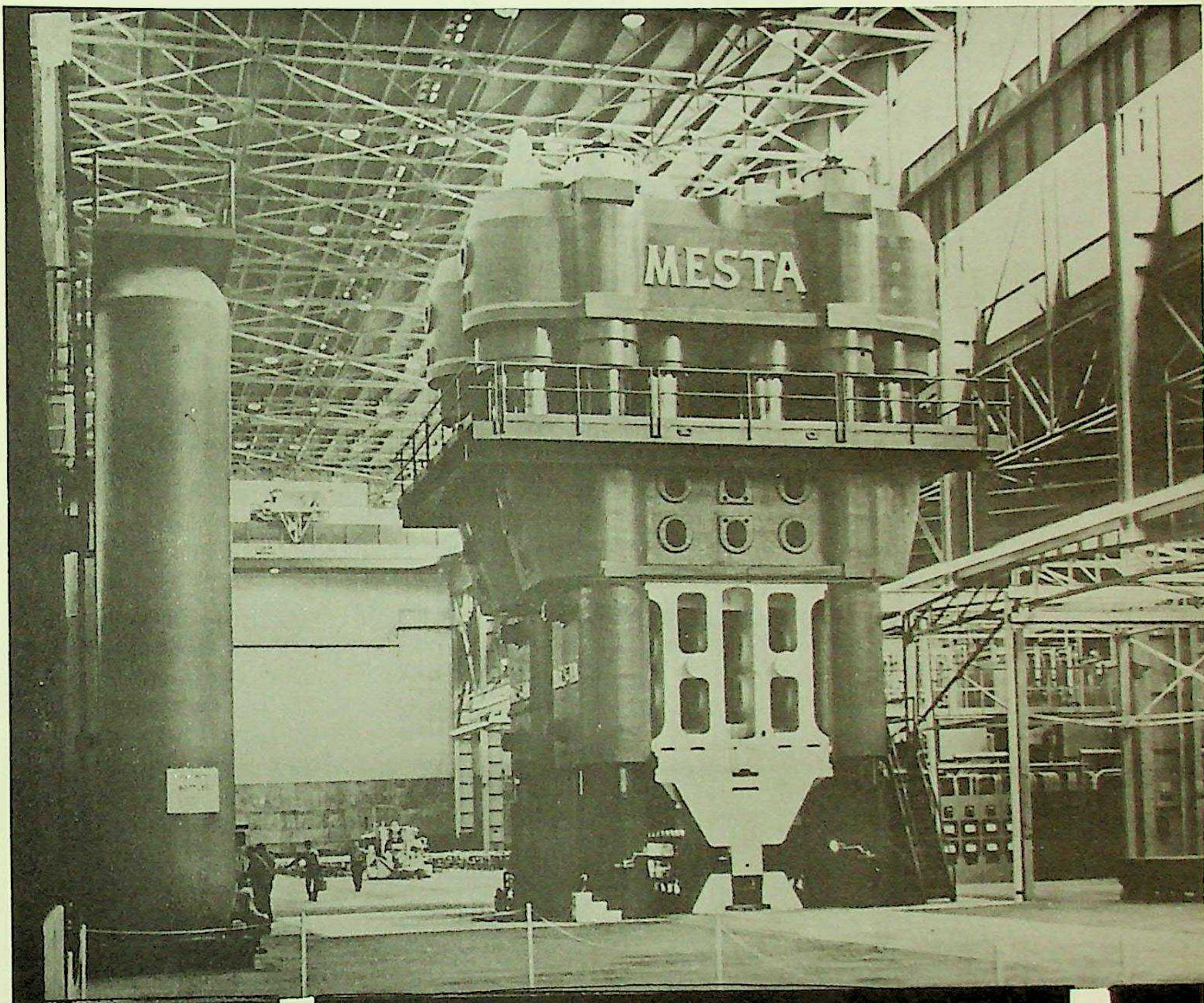
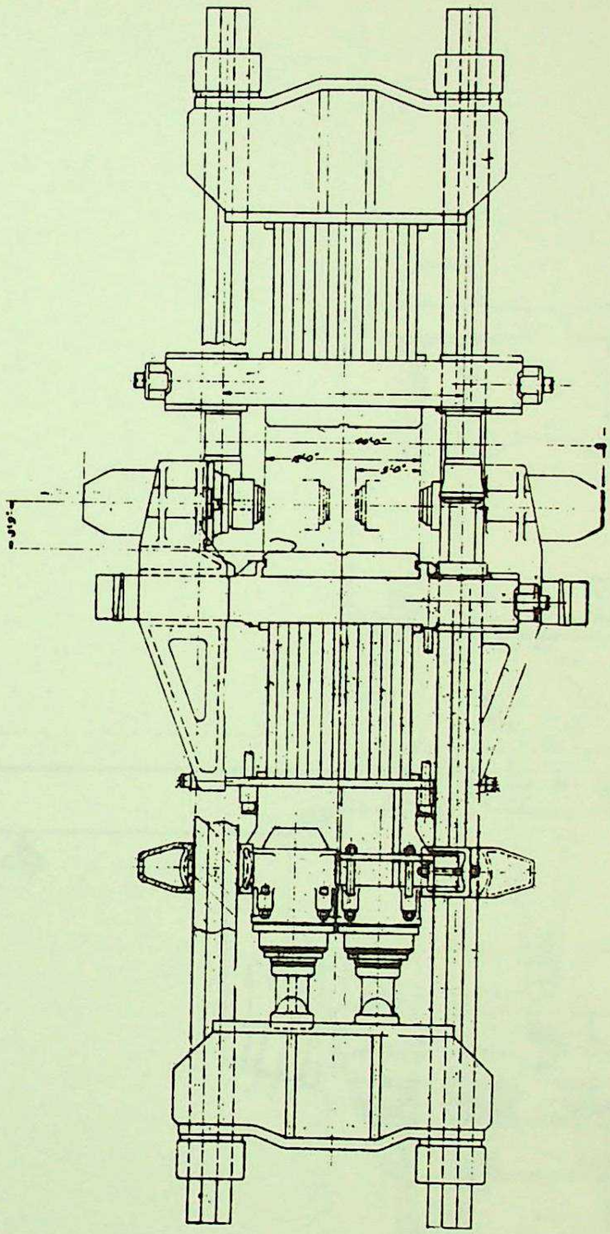
MESTA 50,000 TON PRESS



BIRDSBORO ARCHIVE

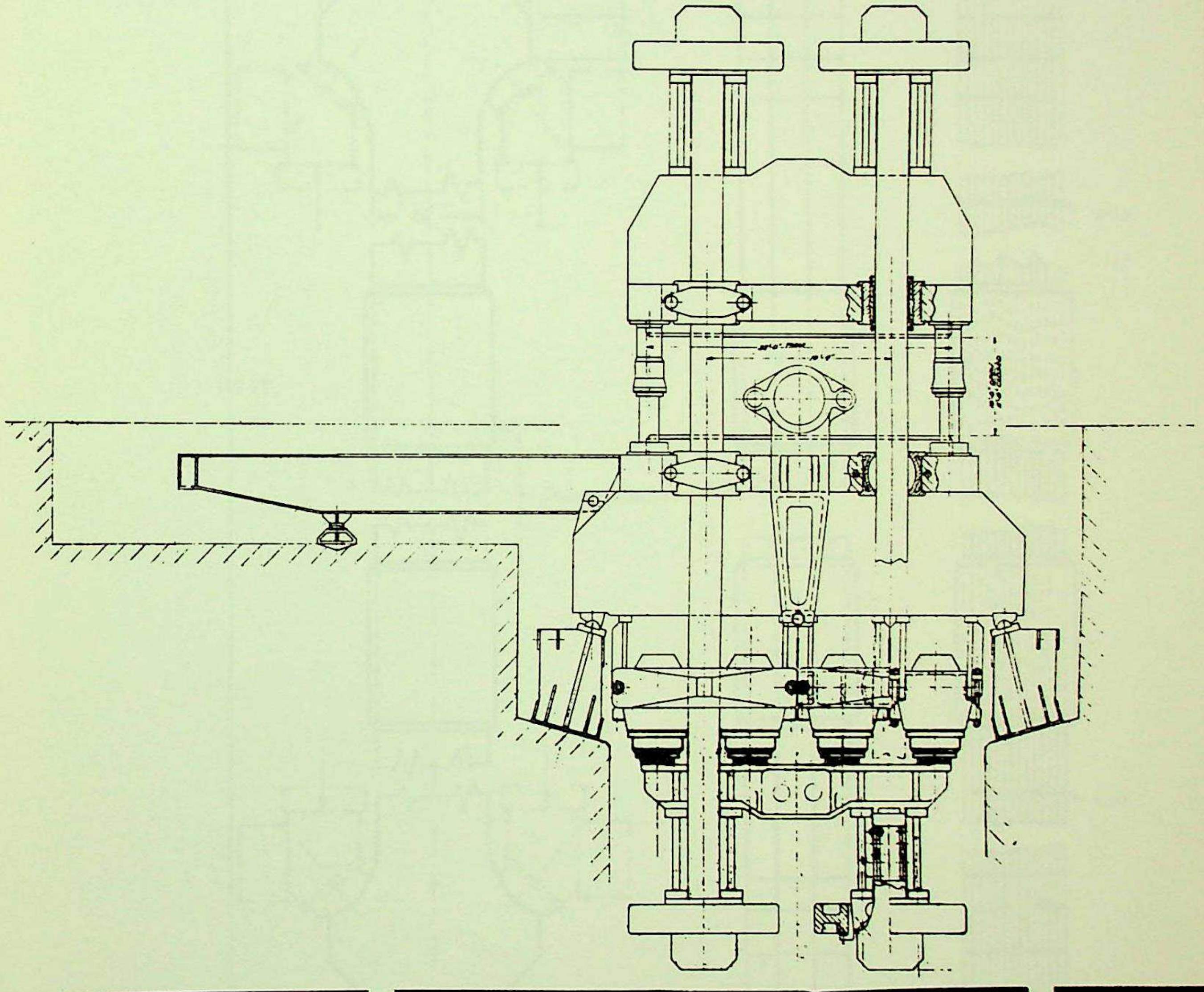
MESTA 50,000 TON PRESS



LOEWY-HYDROPRESS

35,000 TON DIE FORGING PRESS
PROPOSED ARRANGEMENT
RIGHT PART, FRONT VIEW

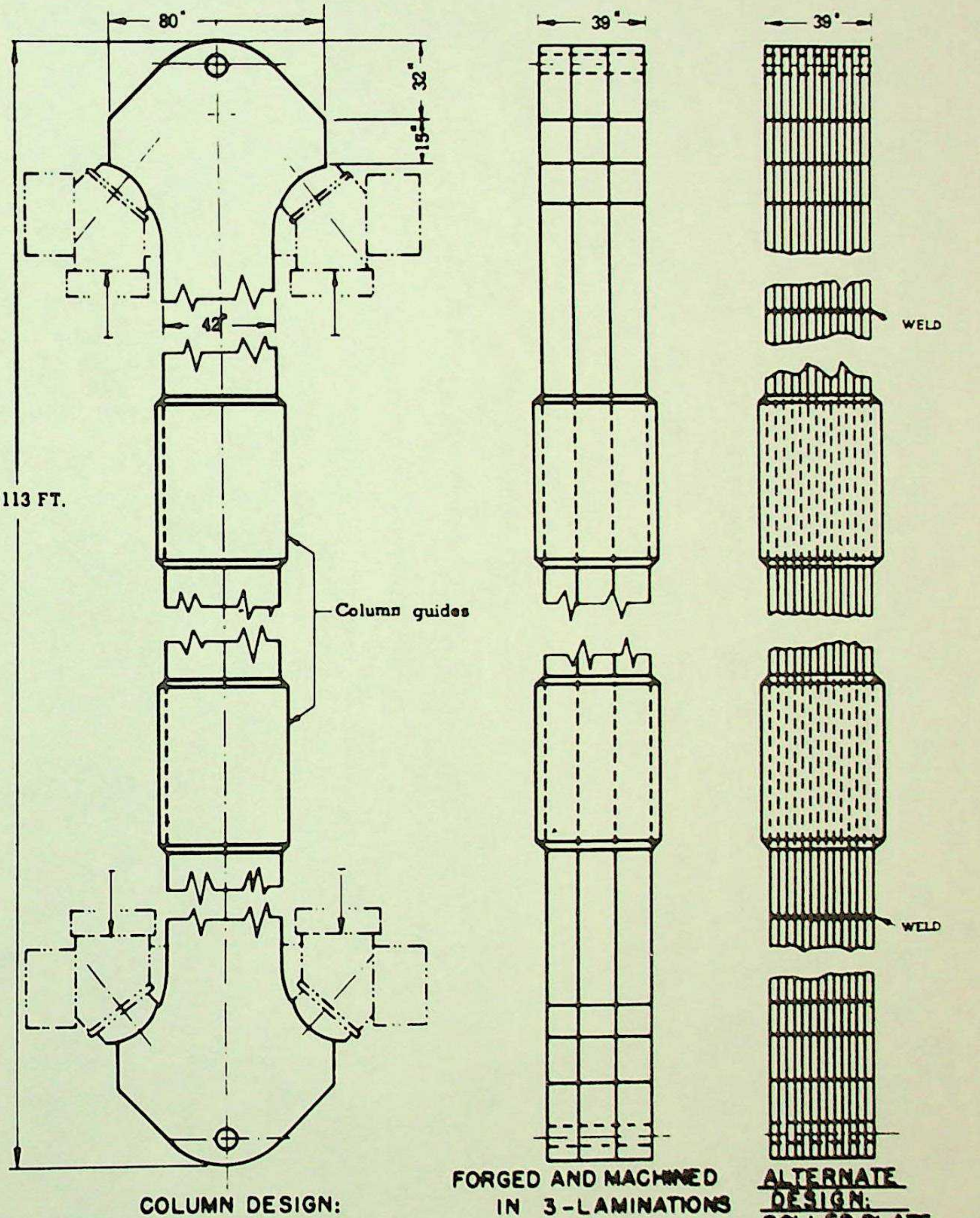
R-128012



HYDROPRESS

35,000 TON DIE FORGING PRESS
PROPOSED ARRANGEMENT
SIDE VIEW

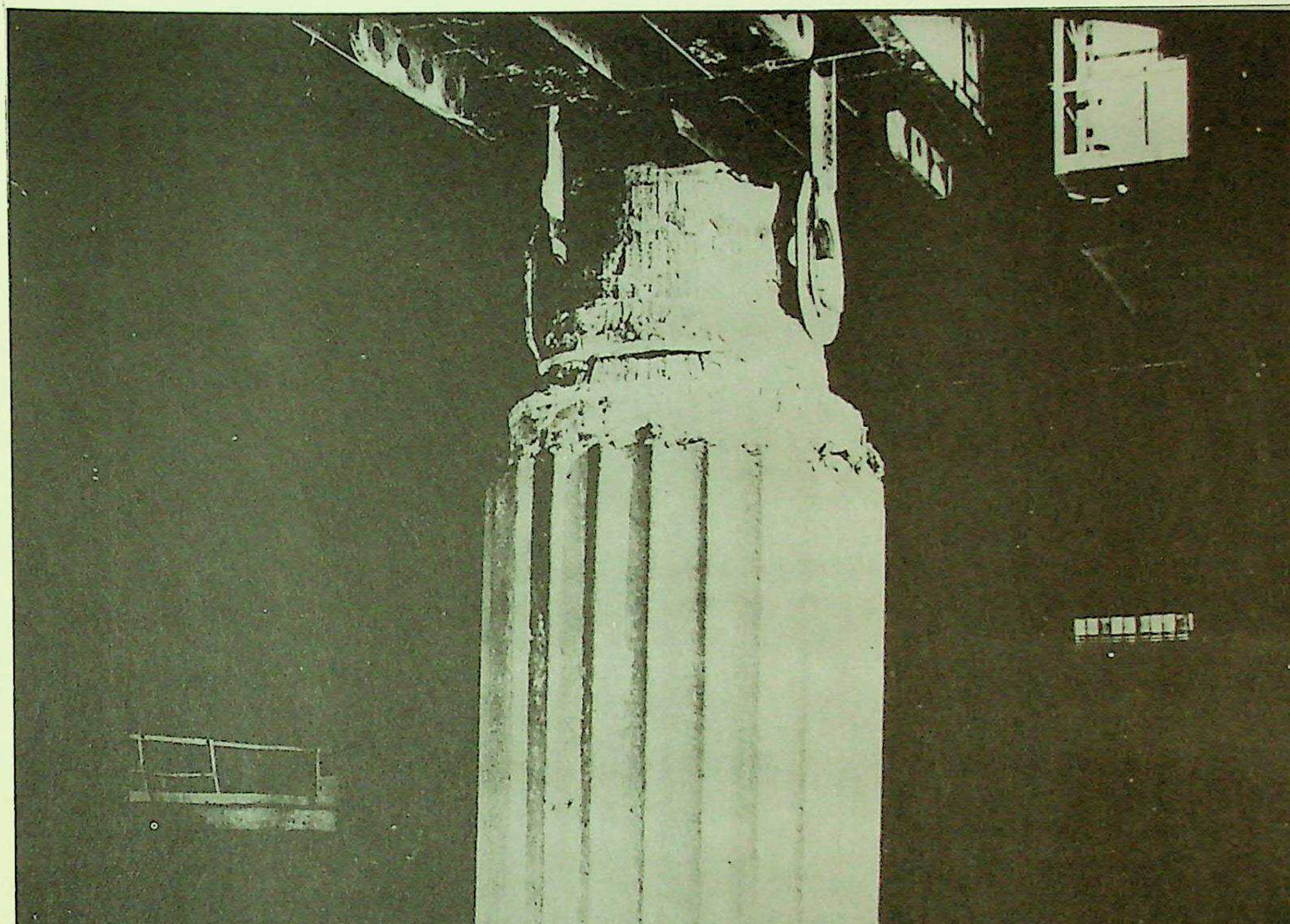
R



75 000 TON CLOSED DIE FORGING PRESS

L. C. C.

12.569

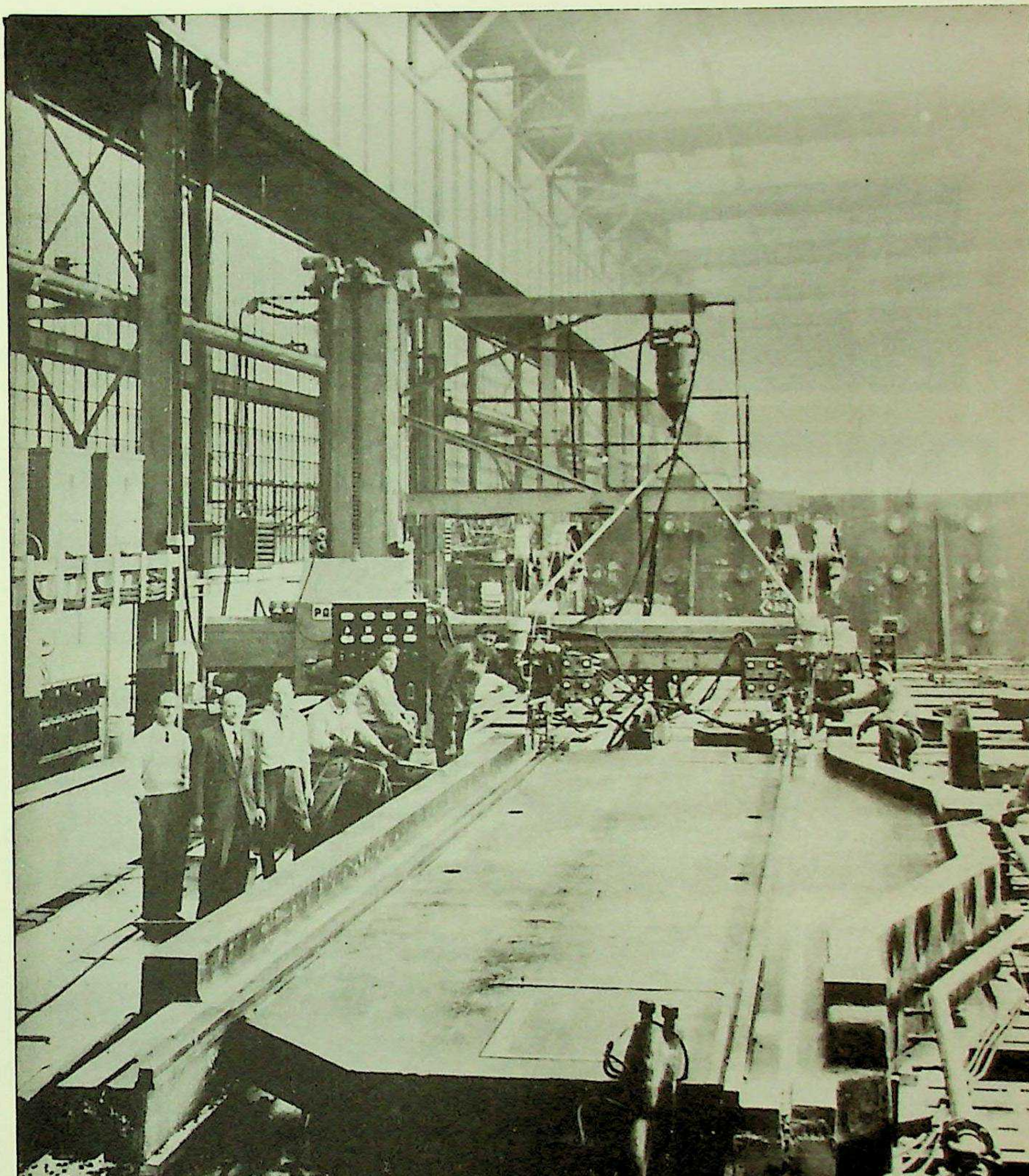


OEWY-HYDROPRESS

50,000 TON CLOSED DIE FORGING PRESS

INGOT, READY FOR FORGING, OF ONE MAIN COLUMN SECTION

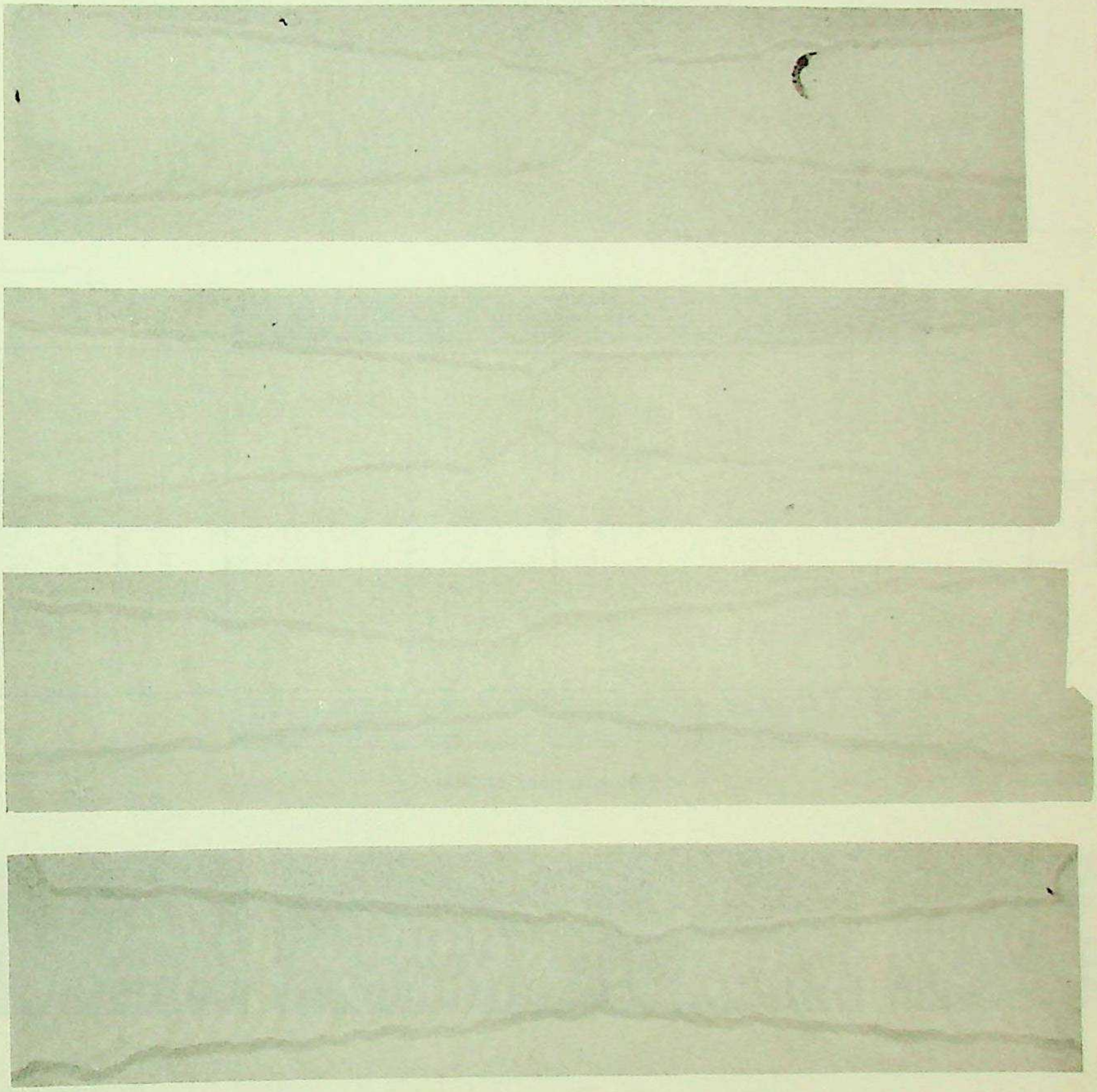
13.111



LOEWY-HYDROPRESS

WELDING OF CROSSHEAD BEAM "MAJOR"

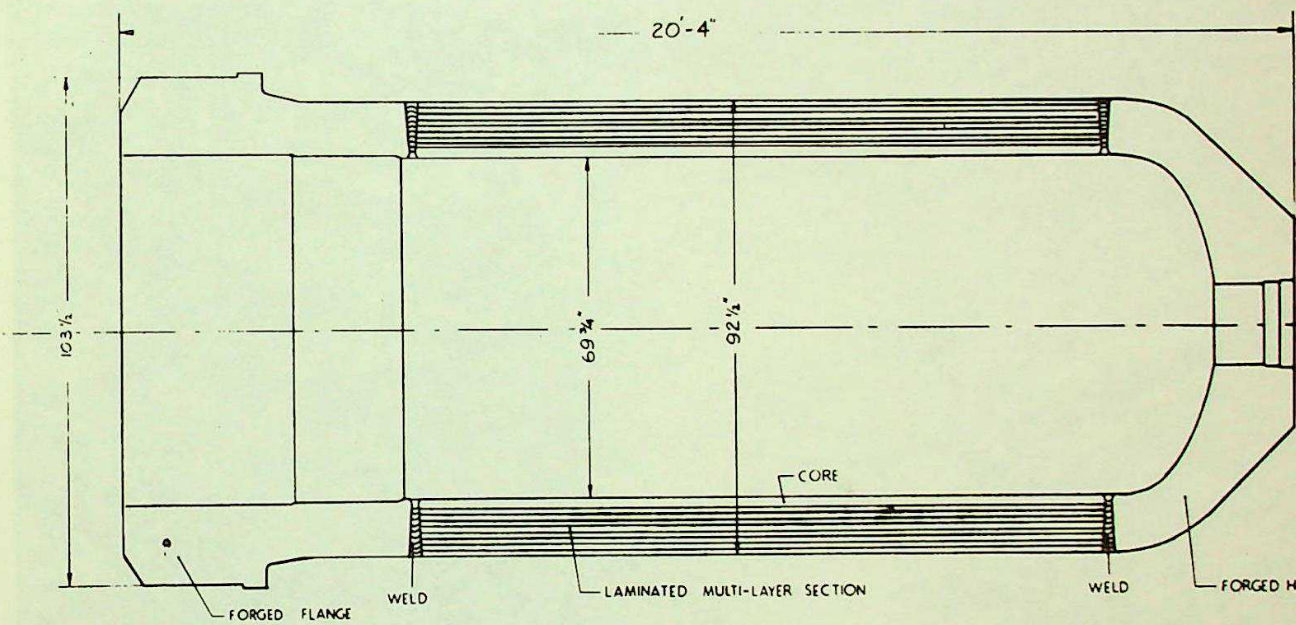
18.2



LOEWY-HYDROPRESS

TREPANNED CORES TAKEN
FROM A LARGE WELDMENT

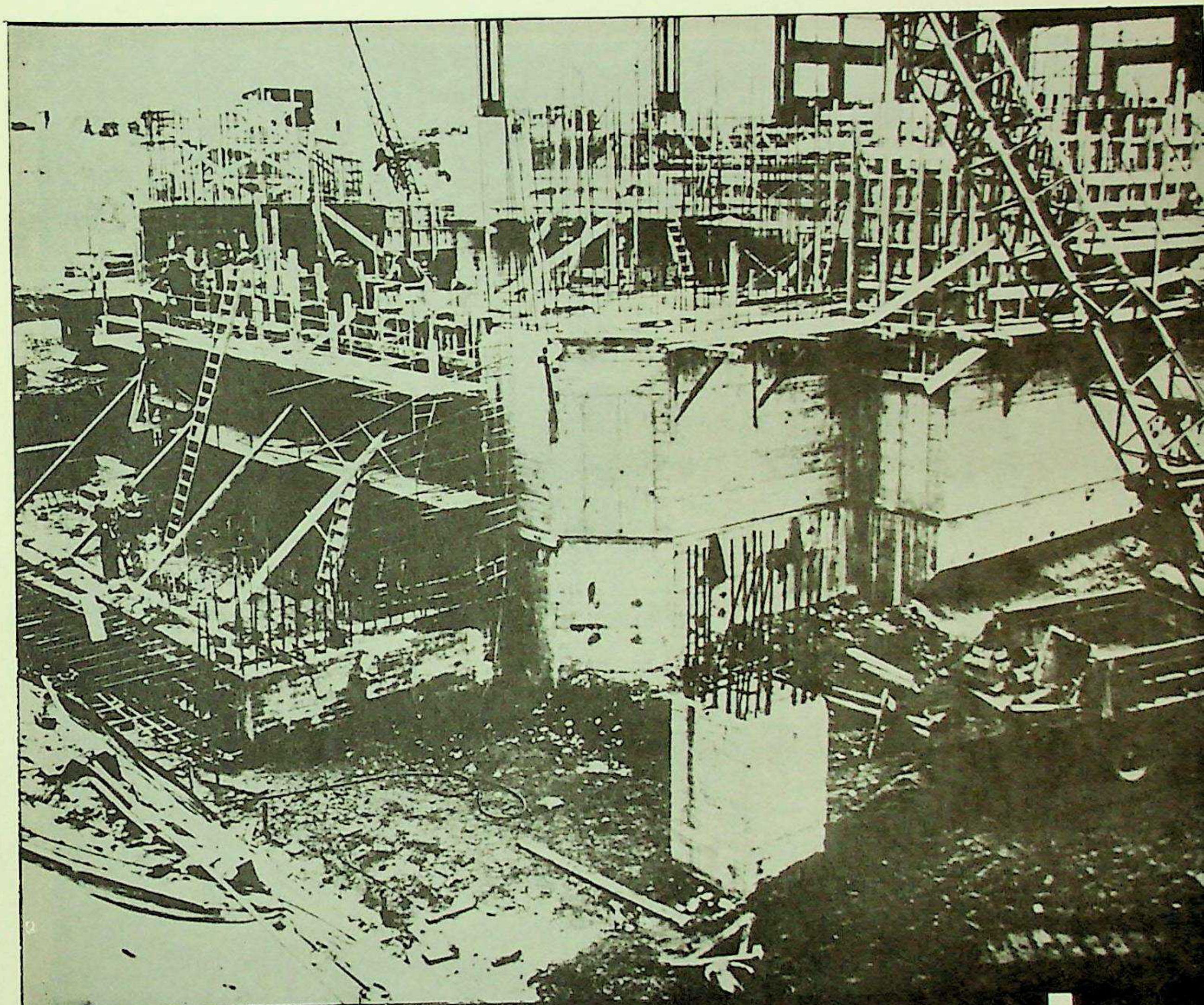
18.932



LOEWY-HYDROPRESS

COMPOSITE MULTI-LAYER MAIN CYLINDER
12,000 TON EXTRUSION PRESS

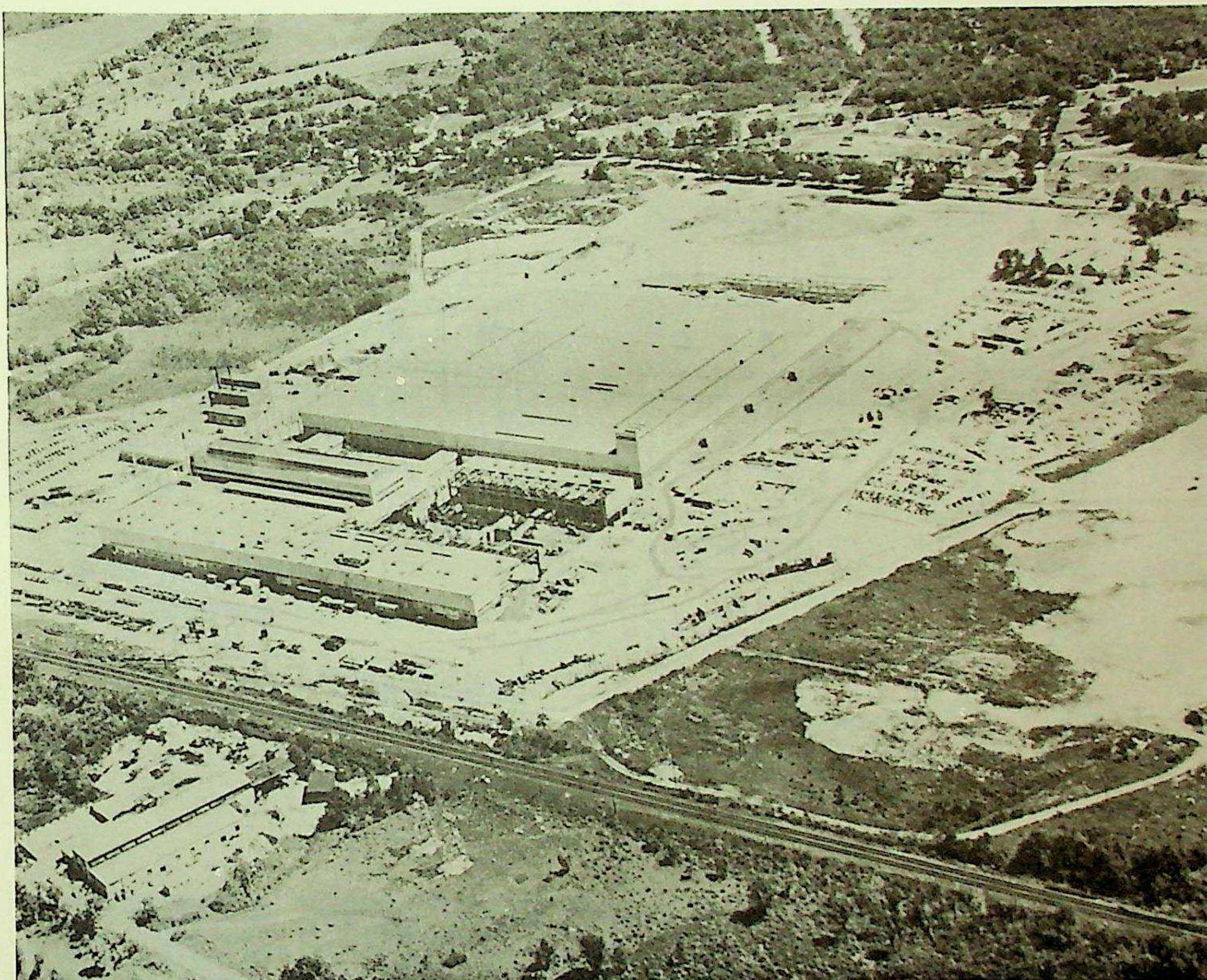
18.155



LOEWY-HYDROPRESS

35,000 AND 50,000 TON CLOSED DIE FORGING PRESSES
CONSTRUCTION WORK AT WYMAN-GORDON SITE
APRIL 16, 1953

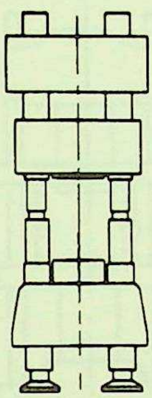
13.314



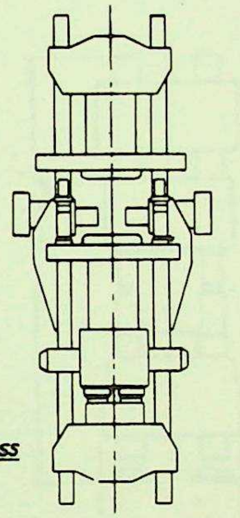
LOEWY-HYDROPRESS

WYMAN-GORDON PLANT, WORCESTER, MASS.
SHOWING CONSTRUCTION SITE FOR LOEWY
35,000 AND 50,000 TON DIE FORGING PRESSES.

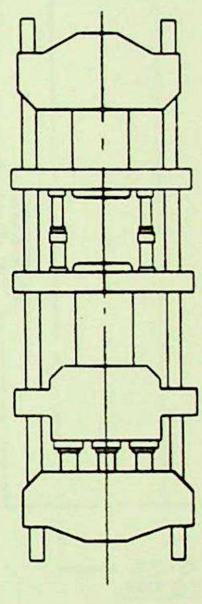
18.072



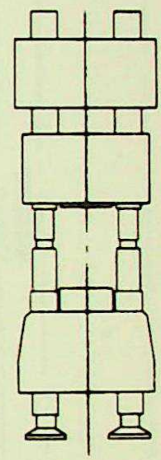
35,000 TON FORGING PRESS
ALCOA
(UNITED ENGINEERING CO.)



35,000 TON FORGING PRESS
WYMAN-GORDON
(LOEWY-HYDROPRESS)



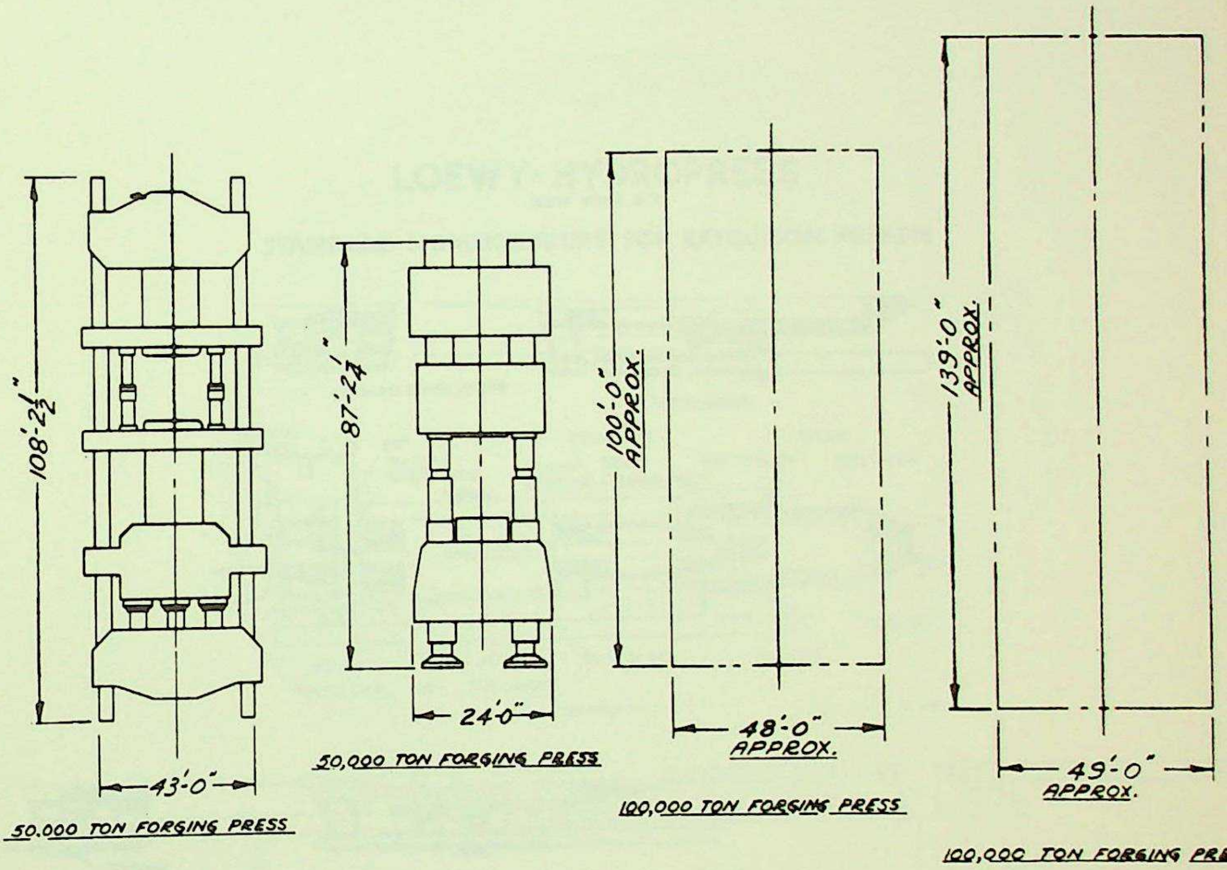
50,000 TON FORGING PRESS
WYMAN-GORDON
(LOEWY-HYDROPRESS)



50,000 TON FORGING PRESS
ALCOA
(MESTA)

BIRDSBORO ARCHIVE

COMPARISON OF LARGEST EXISTING FORGING PRESSES



BIRDSBORO ARCHIVE

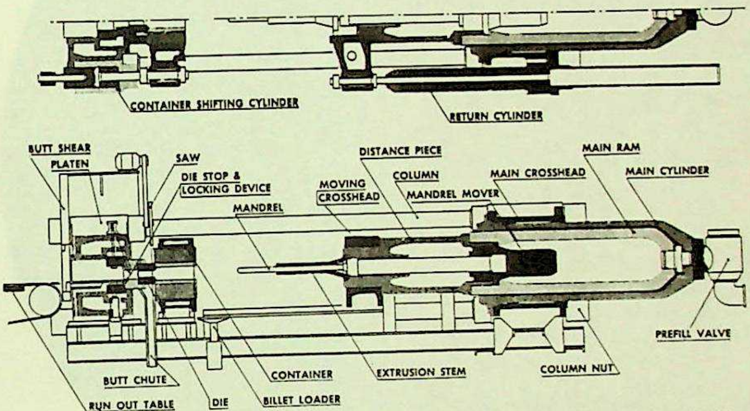
SIZE COMPARISON OF PRESENT TO FUTURE FORGING PRESSES

11

LOEWY-HYDROPRESS

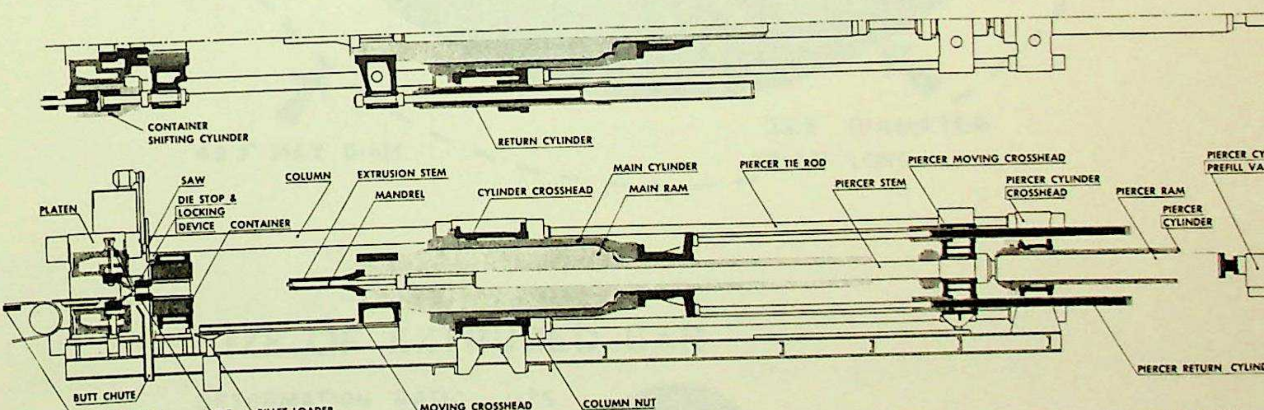
NEW YORK, N.Y.

STANDARD NOMENCLATURE FOR EXTRUSION PRESSES



EXTRUSION PRESS

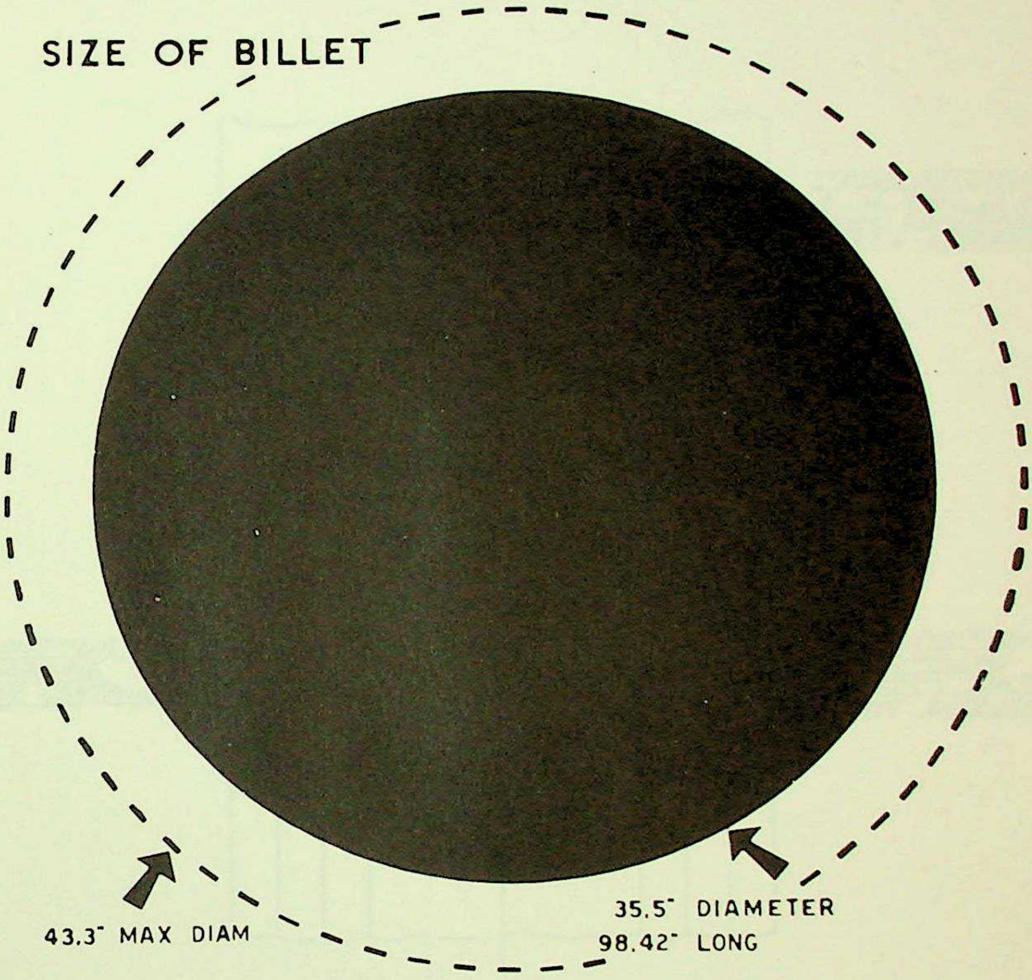
SK 346



EXTRUSION PRESS WITH PIERCER

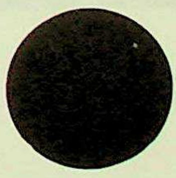
25000 TON EXTRUSION PRESS

SIZE OF BILLET

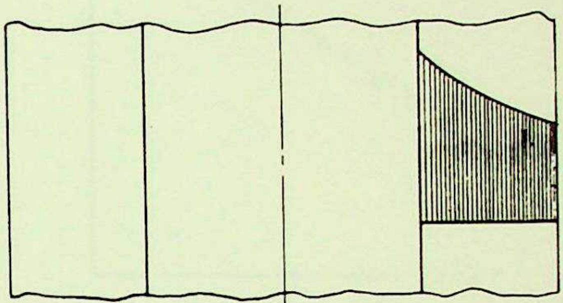


SIZE OF EXTRUDED BAR

DEFORMATION RATIO 1:25

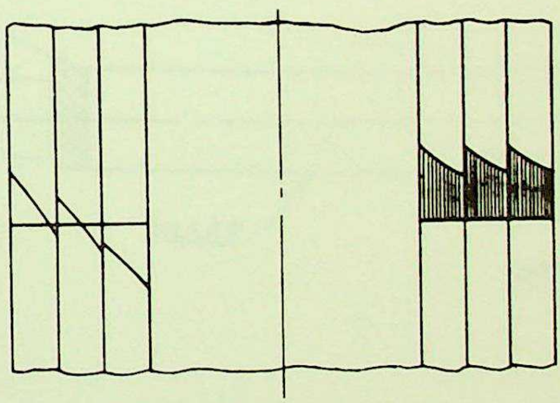


7" DIAMETER
2460" LONG



STRESS DISTRIBUTION
IN THE WALL OF A SOL
TUBE CONTAINER
DURING EXTRUSION

STRESS DISTRIBUTION
IN A COMPOUND
EXTRUSION CONTAINER
AT REST

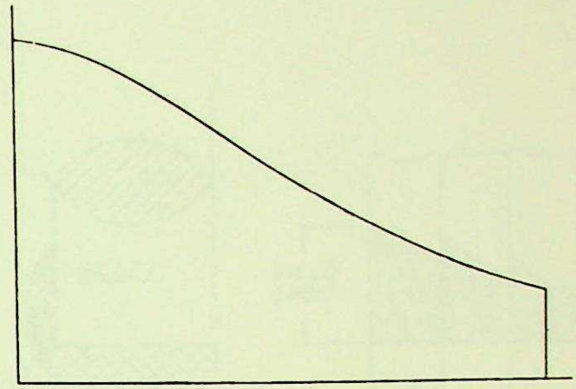


STRESS DISTRIBUTION
IN A COMPOUND
EXTRUSION CONTAINER
DURING EXTRUSION

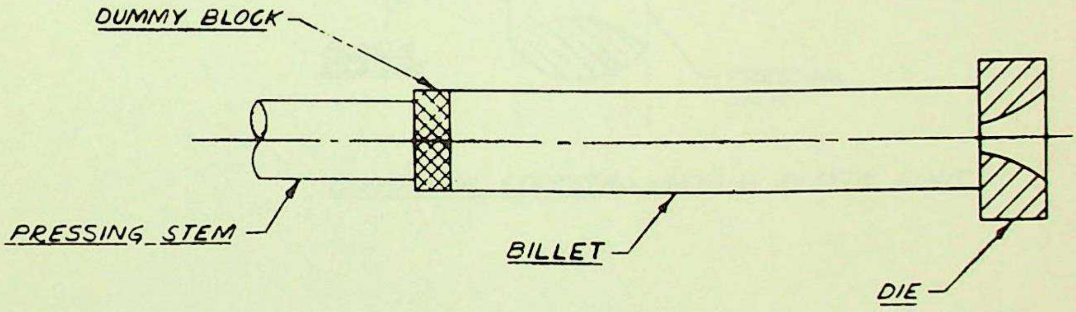
BIRDSBORO

EXTRUSION CONTAINER
STRESS DISTRIBUTION

III

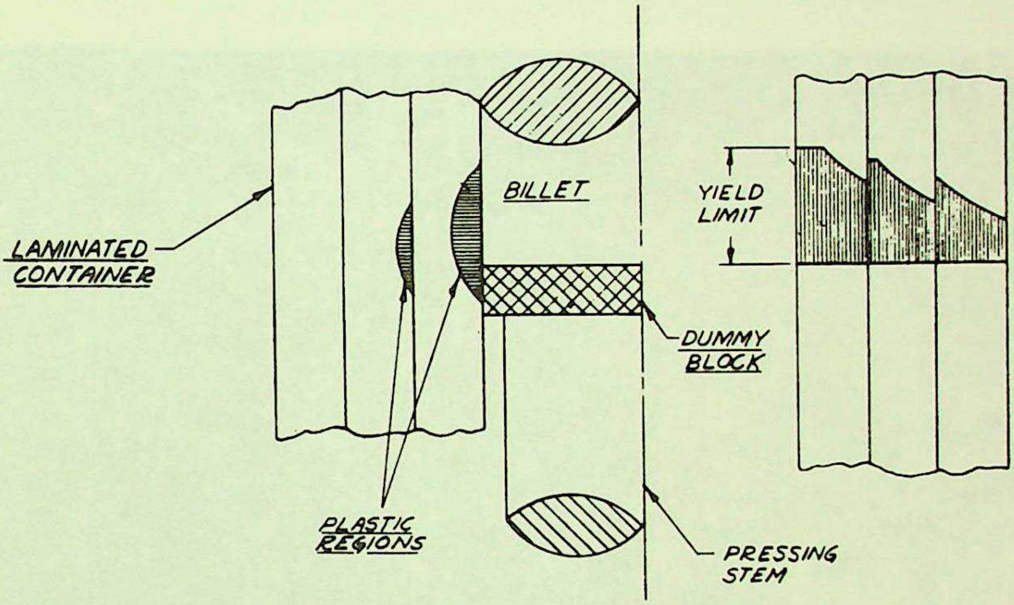


PRESSURE DISTRIBUTION IN THE BILLET



BIRDSBORO

PRESSURE DISTRIBUTION IN BILLET

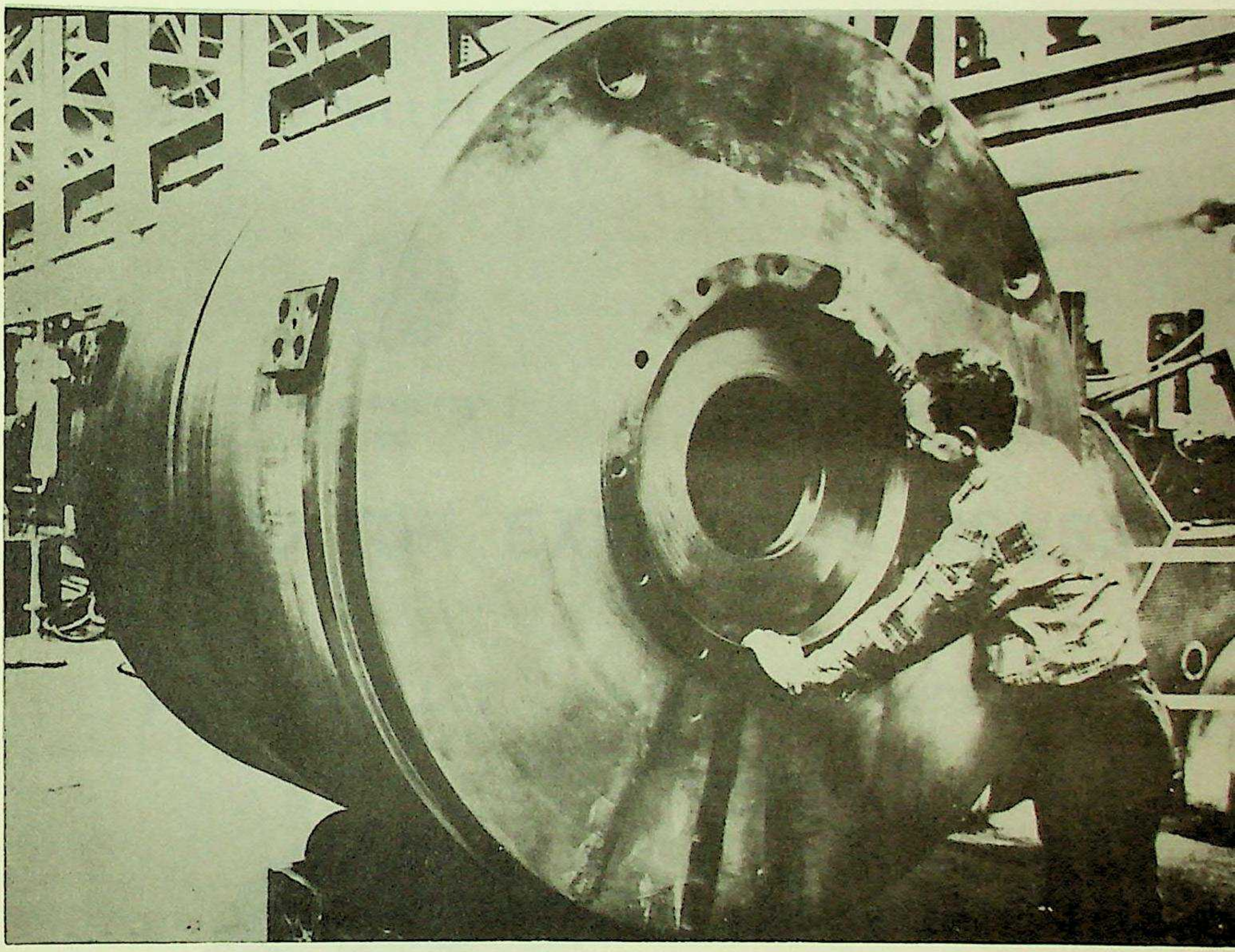


CONTAINER STRESSED BEYOND ELASTIC LIMIT

BIRDSBORO

PLASTIC DEFORMATION OF CONTAINER WHEN STRESSED BEYOND ELASTIC LIMIT

11



LOEWY-HYDROPRESS ARCHIVE

MULTIPLE TUBE CONTAINER FOR LOEWY 12,000 TON EXTRUSION PRESS

18.922

500 TON EXTRUSION PRESS

SIZE OF BILLET | SIZE OF EXTRUDED BAR

DEFORMATION RATIO 1:25

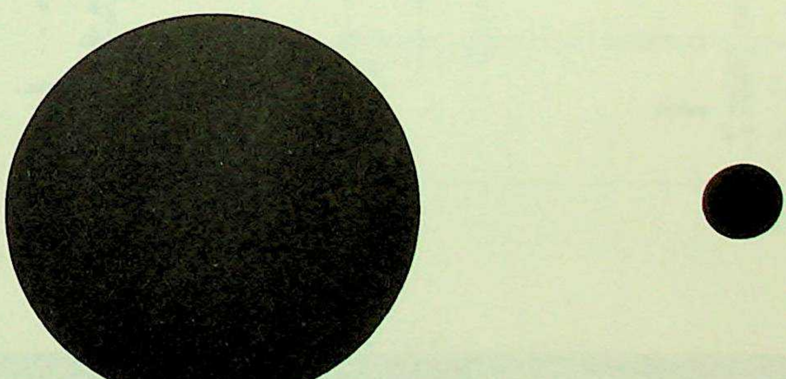
5" DIAMETER
12.6" LONG

0.98" DIAMETER
315" LONG

5000 TON EXTRUSION PRESS

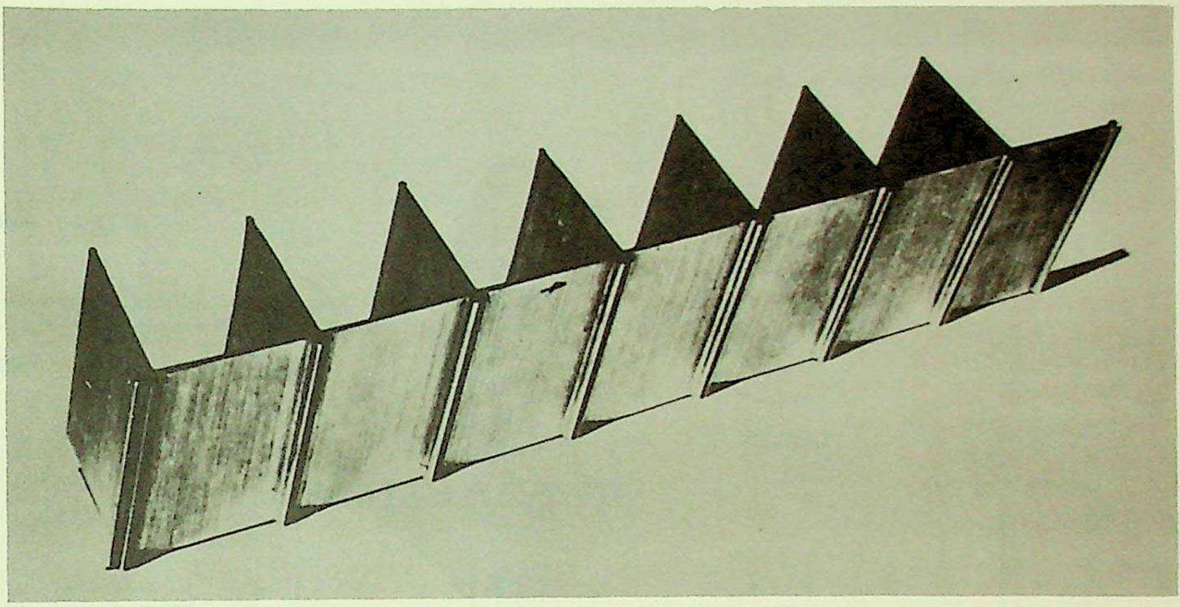
SIZE OF BILLET | SIZE OF EXTRUDED BAR

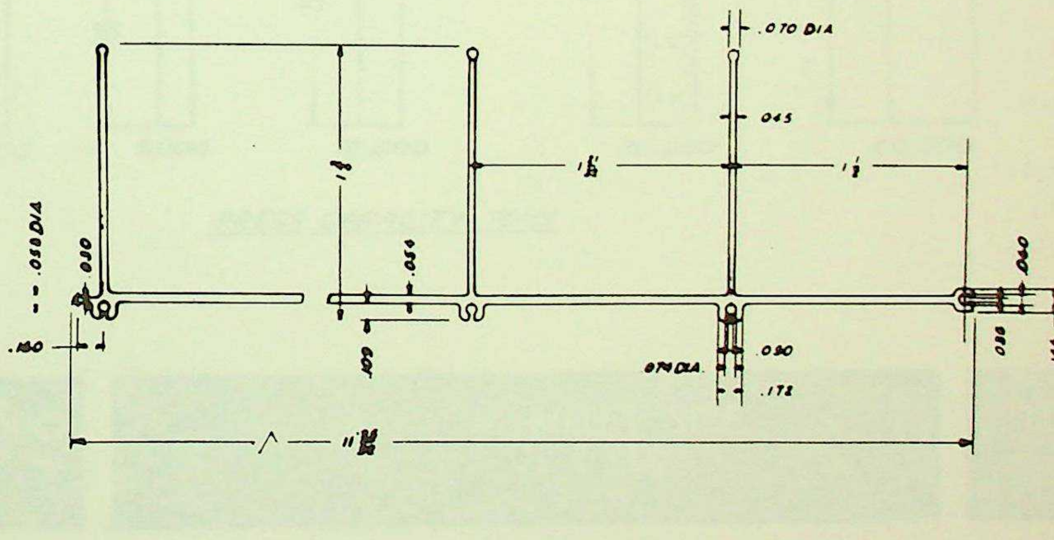
DEFORMATION RATIO 1:25



15.75" DIAMETER
41.35" LONG

3.15" DIAMETER
1030" LONG

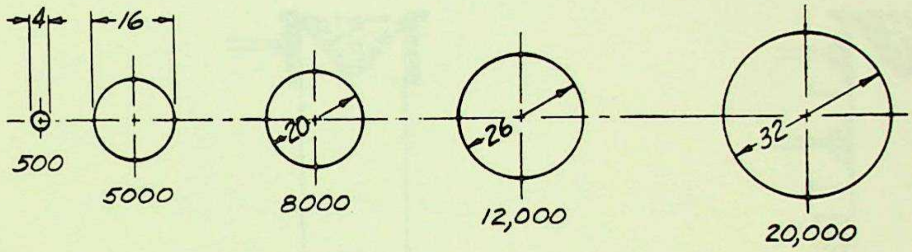




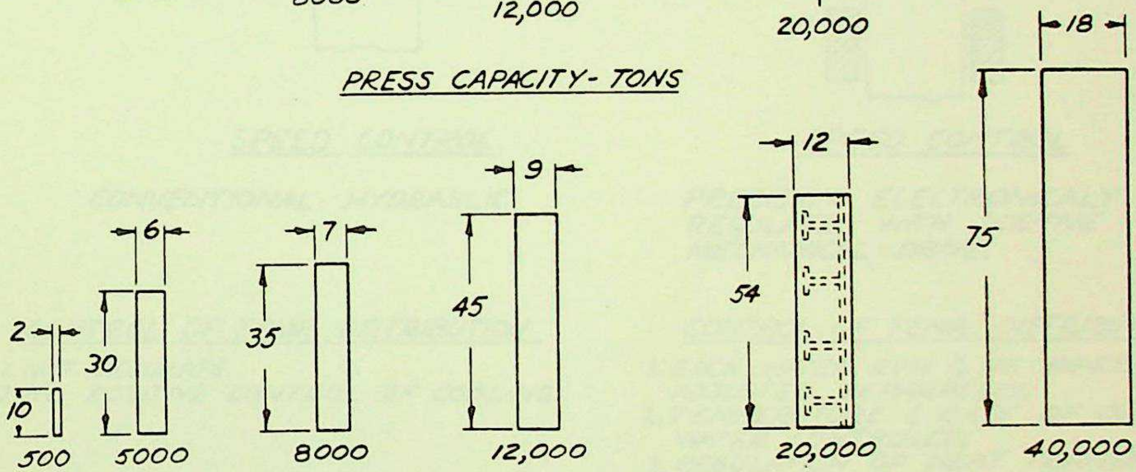
LOEWY-HYDROPRESS

FLAT CONTAINER EXTRUSION

18.69



PRESS CAPACITY- TONS

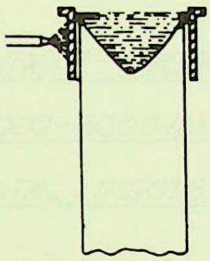


PRESS CAPACITY-TONS

BIRDSBORO

MAXIMUM BILLET SIZE

PRESENT PRACTICE



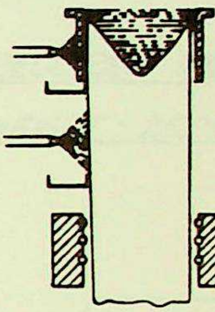
SPEED CONTROL

CONVENTIONAL HYDRAULIC

CONTROL OF TEMP. DISTRIBUTION

1. NOT ACCURATE
2. NO POSITIVE CONTROL OF COOLING.

PRESENT TREND



SPEED CONTROL

PRECISION ELECTRONICALY REGULATED WITH POSITIVE MECHANICAL DRIVE.

CONTROL OF TEMP. DISTRIBUTION

1. EACH WATER RING & ITS WIPER ADJUSTED SEPARATELY.
2. TEMPERATURE & RATE OF COOLING WATER CONTROLED.
3. REGULATION OF HEAT TRANSFER BY ADDING HEAT & INSULATING.

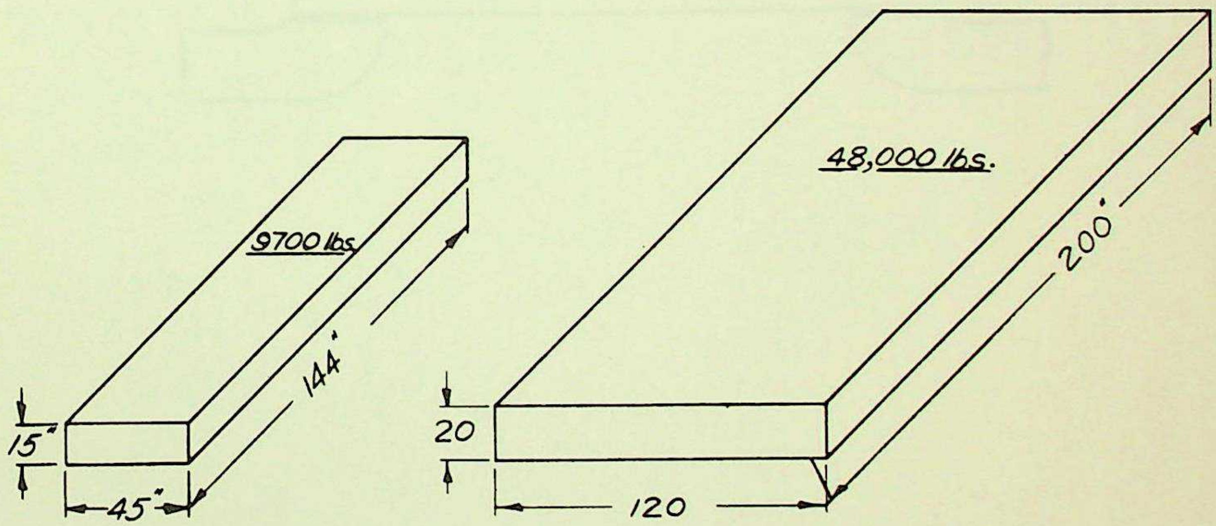
PRESENT INGOT PRODUCTION

WEIGHT : 5000 - 8000 lbs.

EXPERIMENTAL INGOTS : 10,000 - 13,000 lbs.

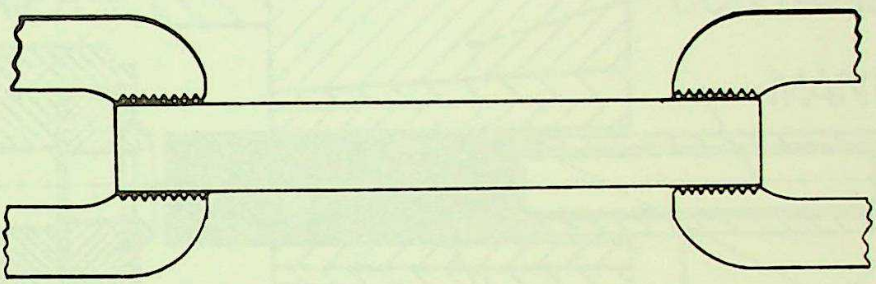
REQUIRED INGOT PRODUCTI

WEIGHT : 25,000 - 50,000 lbs



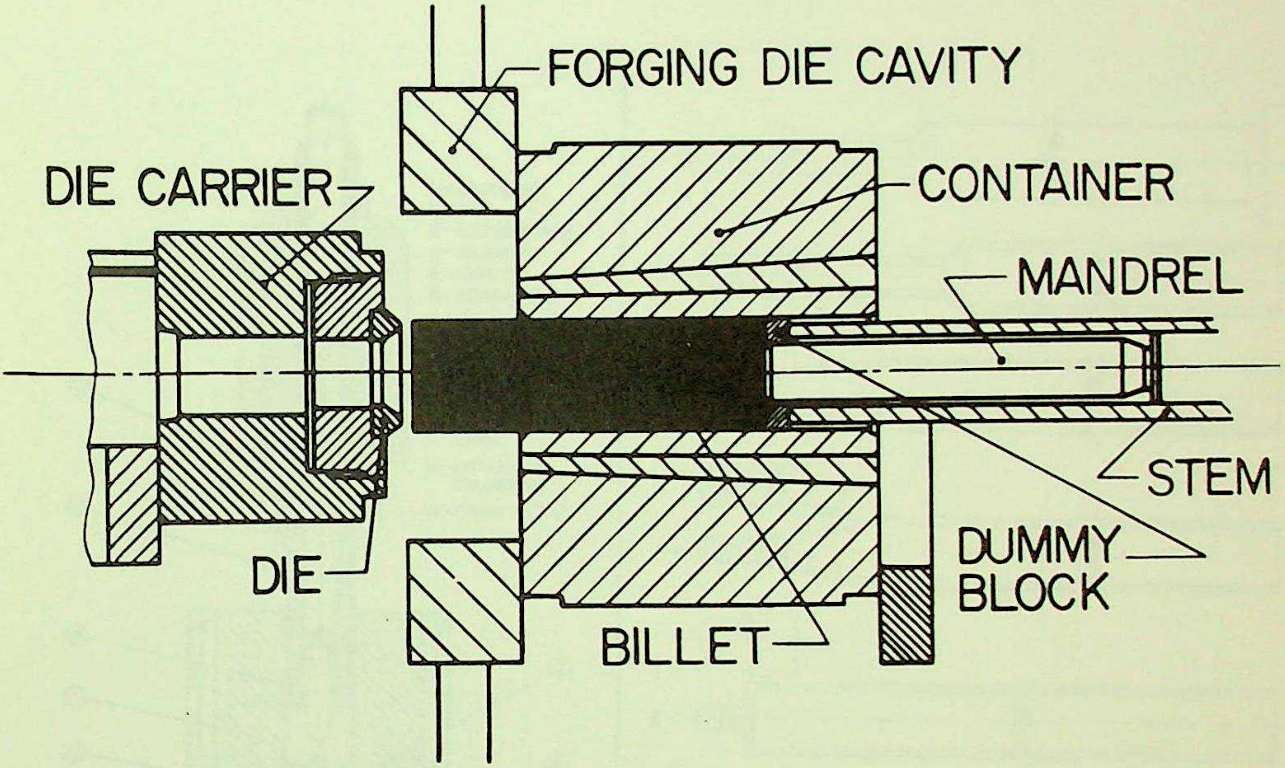
BIRDSBORO

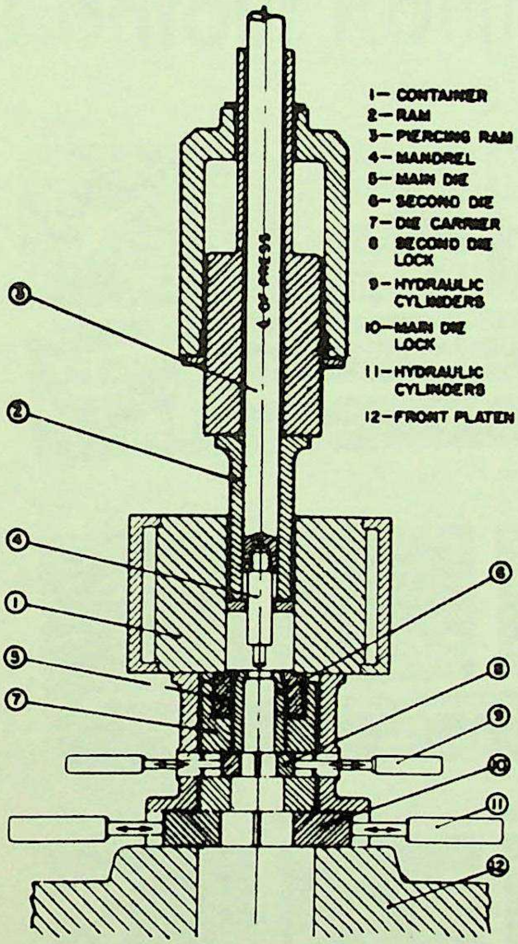
INGOT PRODUCTION REQUIREMENTS

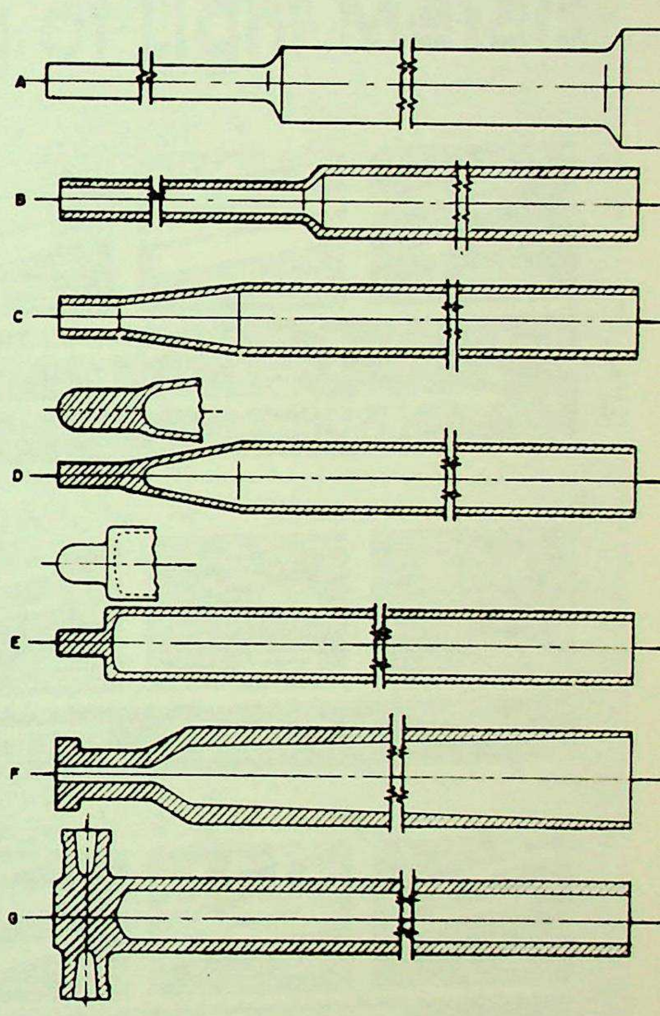


BIRDSBORO

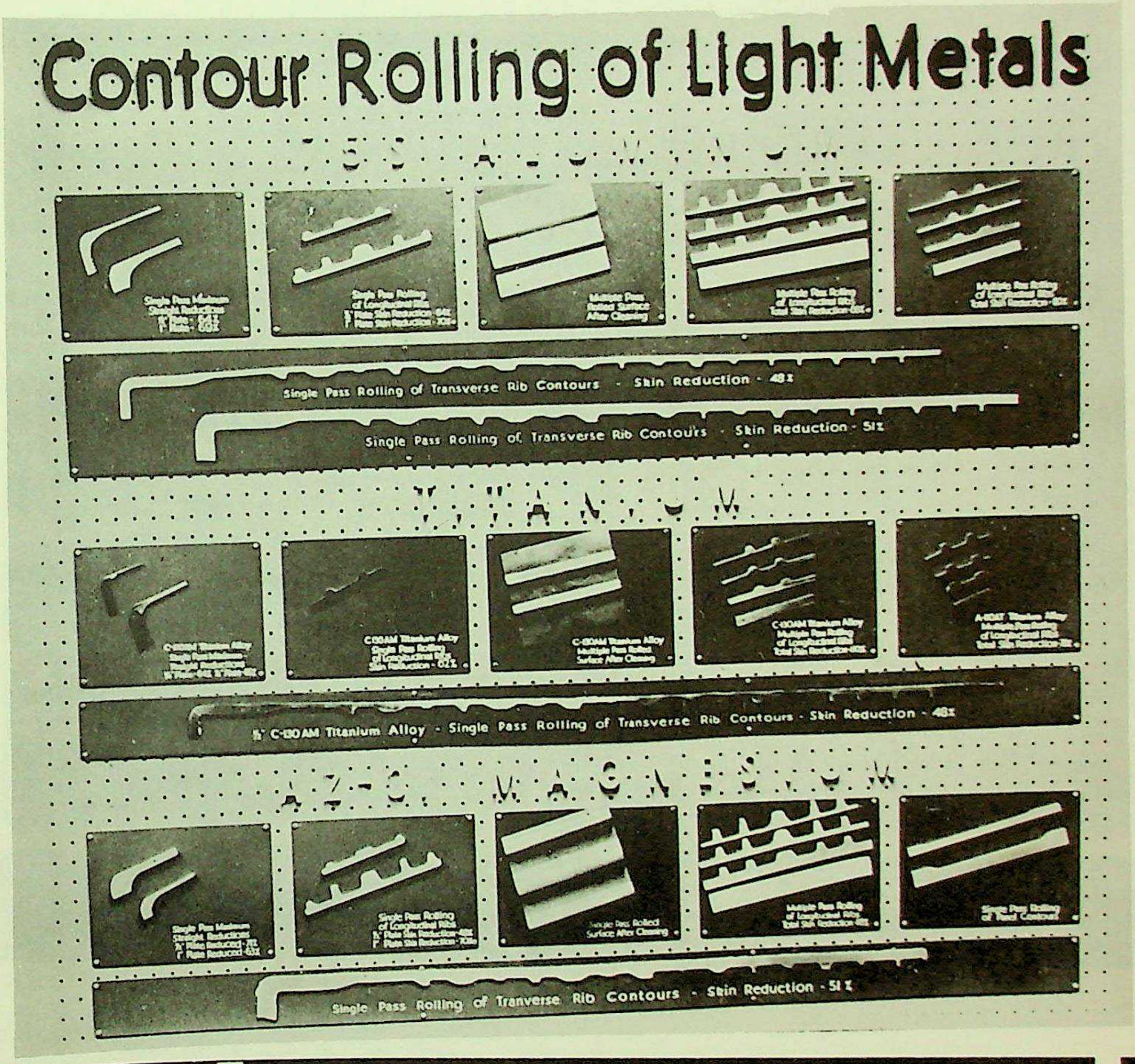
PLATE STRAIGHTENING STRETCHING


FORGING DIE CAVITY
DIE CARRIER
CONTAINER
MANDREL
STEM
DUMMY
BLOCK
DIE
BILLET

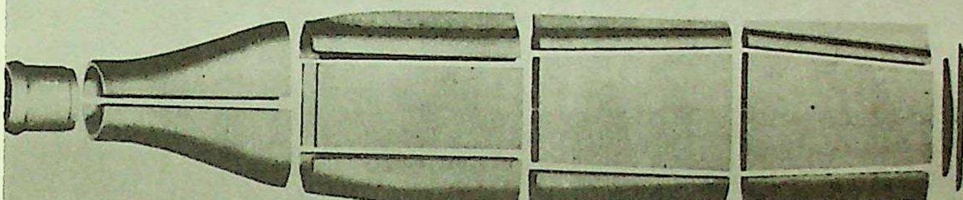

1– CONTAINER
2– RAM
3– PIERCING RAM
4– MANDREL
5– MAIN DIE
6– SECOND DIE
7– DIE CARRIER
8 SECOND DIE LOCK
9– HYDRAULIC CYLINDERS
10– MAIN DIE LOCK
11– HYDRAULIC CYLINDERS
12– FRONT PLATEN
℄ OF PRESS


A
B
C
D
E
F
G

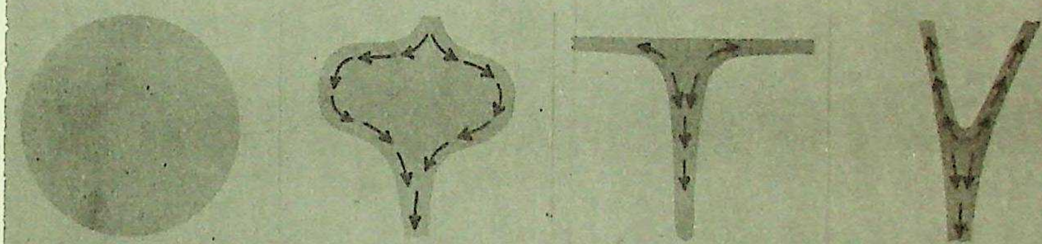
12.849



Courtesy of A. O. Smith Corp.



Partially exploded view of typical Smithway 9½' hollow steel propeller blade showing individual sections prior to assembly. These parts are precision forged and formed to close matching tolerances to permit subsequent easy and rapid joining through high strength flash welds.

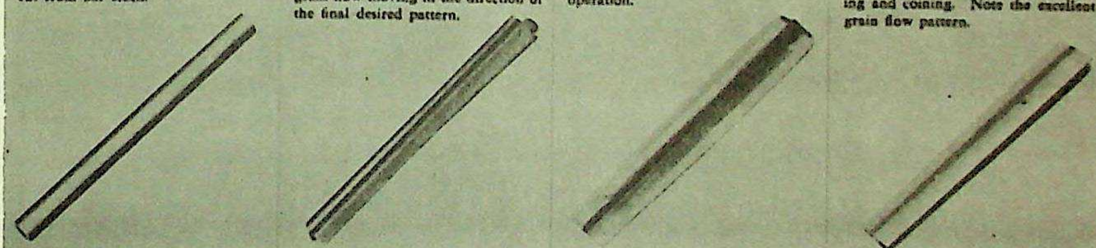


Initial forging blank for edge section cut from bar stock.

Part after first forging hit. Note the grain flow moving in the direction of the final desired pattern.

Part elongated through a roll forging operation.

Part as finally formed by forge folding and coining. Note the excellent grain flow pattern.



LOEWY-HYDROPRESS ARCHIVE

STAGES IN ROLL FORGING A HOLLOW STEEL PROPELLER BLADE

18.694